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A Study to Develop Strategies for Proactive Water-Loss Management

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A STUDY TO DEVELOP STRATEGIES FOR PROACTIVE WATER-LOSS MANAGEMENT

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A STUDY TO DEVELOP STRATEGIES FOR

PROACTIVE WATER-LOSS MANAGEMENT

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With special appreciation
To
My Mom:
Ho Sang Jeong
And
My Brother:
Jin Ho Park

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LIST OF SYMBOLS AND ABBREVIATIONS

ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
AWWARF	AWWA Research Foundation
CCWA	Clayton County Water Authority
CWS	Community Water System
ELL	Economic Level of Leakage
EPA	Environmental Protection Agency
IWA	International Water Association
MGY	Million Gallons per Year
NRW	Non-Revenue Water
O&M	Operation and Maintenance
OFWAT	Office of Water Services
RFC	Raftelis Financial Consulting
UFW	Unaccounted-for-Water

SUMMARY

Water conservation is one of the important policy concerns. However, most water conservation practices have focused primarily on reducing use by customers. Since a large amount of water lost in supply systems causes water providers to lose money, resources, and reliability, and the current passive approach cannot deal with water losses effectively, a proactive approach is necessary for water-loss management. The goal of this study is to help policymakers and water utilities develop strategies that proactively solve water losses. To develop strategies for water-loss management, it is essential to identify key factors that determine the level of water losses as well as the factors that encourage the adoption of the innovative control practices. Using three different datasets and statistical methodology, this study analyzed the factors associated with water losses and utilities' responses to the problems. Based on case studies, this study explored managers' perceptions about the adoption of water-loss management and identified organizational characteristics that may influence management's decisions to adopt such strategies.

Operational and Maintenance (O&M) factors had the most significant impacts on water losses. In particular, system size, represented by total production or population served, and infrastructure rehabilitation were crucial factors. The effects of some internal factors on water losses were predicted but those of several internal factors were rather unclear and relatively complicated. This study confirmed that utilities were more likely to be motivated to combat water losses if certain external conditions, such as higher water demand, limited resource availability, and institutional pressure exist. This study found several internal and external factors associated with the adoption of proactive water-loss management; however, internal factors seemed to dominate in the decision-making processes over such adoption. The utilities that have already adopted proactive water-loss management seem to be more amenable to adopt new practices because they have certain characteristics and their managers have more positive perspectives.

The findings suggest several policy implications and recommendations for the water industry. Finally, this study discussed limitations of the study, and suggestions for further studies.

CHAPTER 1

INTRODUCTION

Despite a seeming abundance of water, the United States Environmental Protection Agency (EPA) predicts that more than 70 percent of the United States will suffer a scarcity of water within the next ten years, regardless of drought conditions.[1] Economic and population growth exacerbates this problem, the demands for water continue to increase, and the quality of water continues to decline. To meet increasing demand, water suppliers have relied heavily on supply management, focusing on the expansion of systems. Supply management becomes more and more problematic and costly[2] as water becomes scarce; this necessitates the use of water conservation practices. Most states have implemented a variety of water use restrictions and conservation programs that focus primarily on reducing use by customers. However, Hyman (1998) claims that "some of the biggest returns can be made by the supplier reducing the water it wastes" (p.441).

As some water is necessary for the production and operation of water utilities, all the water produced cannot be delivered to their customers. However, a large amount of water seems to be lost beyond that which is unavoidable.[3] Wallace (1987) estimated that

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[1] Refer to Water World Online: "U.S. EPA works towards raising public awareness on water efficiency."
[2] As water resources become depleted, Frederick (2002) argues, the capital and operating costs of developing additional supplies become significantly high and yield diminishing returns, making new water supply projects unpopular from an economic standpoint.
[3] International standard methods are available to estimate "unavoidable leakage" or "economic level of loss (Lambert et al. 1999), but many of the U.S. water utilities do not apply the methods and do not even seem familiar with these terms; thus, there is no reliable information about how much water loss is avoidable or

the value of "unaccounted-for" or lost water in the U.S. was between $158 and $ 800 million per year, and Hyman (1998) claimed that 20 to 30 percent of water produced had been wasted across the U.S. water supply systems. According to the U.S. Geological Survey (USGS) 1995 water use data, the category of “public use and losses[4]” represented almost six billion gallons per day (GPD), or 14.88% of the total withdrawal for public supply. Based on an American Water Works Association (AWWA) 2000 survey, Laughlin (2001) claimed that the U.S. water industry lost or failed to charge an average of 16% of delivered water or 2.45 billion GPD. Thornton (2002-a) estimated that the value of total water losses per capita per year in the U.S. was $13.58. Given the lack of reliable data on water losses[5], such estimates might not represent true measurements, although they still provide insights into the vast quantities of water lost in the U.S. water systems.

The production of water requires expensive treatments that consume energy and chemicals as well as raw water withdrawn from the environment, and it requires extensive labor and capital and other system operation and maintenance.[6] Thus, the loss

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reasonable economically (Cummings, Norton, N., Norton, V., & Wilson, 2004). However, EPA recommends that water utilities reduce unaccounted-for-water (UFW) to 10% through water-loss management programs (refer to: http://www.epa.gov/OW-OWM.html/water-efficiency/munitips.htm). Thus, a 10% loss can be a proxy for what a water utility would maintain.

[4] By putting two different water uses into one category, USGS data provides confusing information on water losses. Given the lack of reliable water-loss data, however, Kunkel (2003) suggests that it can be used for a good first guess.

[5] Wallace (1987) argues that many water utilities use confusing water-loss terminology, so it is difficult to obtain reliable, comparable data on water losses. Thornton (2002-a) attributes the data limitations to unreliable percentage measures, a lack of standard procedures to gauge water losses, and inconsistent terminology.

[6] According to the U.S. EPA 2000 Community Water System (CWS) Survey, 71 percent of CWS provides treated water for customers and the percentage of systems providing treatment has increased since 1976. Even water systems not providing any treatment consume a large amount of energy to deliver water to customers, so any water losses in the systems is deeply related to other resource waste.

of water in supply systems leads to waste of other valuable resources– particularly, energy resources.[7]

Leaks and breaks are the major causes of water losses in distribution systems. Many water utilities repair only visible or reported leaks and breaks, and they do not address less visible or unreported leaks that damage water infra-systems in the long-term. This passive approach to dealing with such problems weakens the security and reliability of many systems. In summary, the loss of some valuable water that could have been delivered to customers causes water providers to lose money, resources, and reliability.

Fortunately, many of water losses are preventable or avoidable. The AWWA Water Loss Control Committee (2003) insists that loss-recovery is one of the most promising water resource programs. One gallon salvaged from a distribution system is more valuable than several gallons taken from the environment because of saved resources and costs. By transforming avoidable losses to alternative sources of water, water utilities create opportunities to utilize resources in a more efficient way. Several specific cases prove the cost-effectiveness of water-loss management. Through its system-wide leak detection program, the Clayton County Water Authority (CCWA) in Georgia has saved seven dollars worth of water for every dollar spent; and in 42 months, the CCWA claims that it has recovered over $2.6 million worth of lost water, which more than covers the $380,000 cost of the leak detection program.[8]

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[7] As the water industry is the largest single user of all electricity generated in the U.S., any waste in the water industry can affect overall energy efficiency. Thus, the importance of the integration of energy use into water planning has been emphasized. (Cohen, Nelson, & Wolff, 2004.).

[8] Refer to Water World Online: "Clayton County, Ga., program focuses on leak detection"

According to Seidenstat (2005), U.S. water utilities have attempted to apply a variety of management innovations such as effective customer involvement, systematic water infrastructure rehabilitation, automatic meter-reading programs, application of a geographic information system (GIS), and aggressive financial strategies. Unfortunately, such innovative practices, especially proactive water-loss management, have not been widely applied by the U.S. water utilities. On the contrary, many utilities limit their response to water losses to customers' properties rather than broaden it to losses within their own systems. Constantinides (2002) argues that some utilities are taking actions against water losses as a "one-off project" rather than making sustained efforts to reduce waste and losses, which results in ineffectiveness. According to Agthe, Billings, and Buras (2003), there is little incentive for innovations in the U.S. water industry because of a protected market and the lack of profit incentives, which explains why just a few utilities have adopted innovative technologies and management tools to deal with water losses proactively.

Given the few incentives for innovations, why do some water utilities adopt innovations? What factors encourage or discourage the decision to adopt or not to adopt such innovations? This study focuses on innovations related to water losses. Water-loss management is a new concept to most water utilities familiar with the passive approach. This study makes a clear distinction between innovative and passive approaches. While the passive water-loss management relies on engineering solutions and repairs only significant or reported leaks, innovative water-loss management is a "proactive" approach. A "proactive" approach focuses on the prevention and control of water losses and also considers the efficiency of the overall water supply systems by not just relying on engineering solutions. Innovative water-loss management encompasses active leak detection/ repair programs, pressure management, theft control, and system improvement such as meter upgrades, infrastructure rehabilitation, and comprehensive system-wide water accounting system.

Although no studies consistently identify the most important factors that could affect management's decision to adopt innovations, researchers have proposed a variety of factors. Such factors include but are not limited to institutional pressure, market structure, and organizational characteristics – structure, climate, and leadership (Cooper, 1998). In order to encompass all possible factors, researchers employ integrated perspectives of different theories (Barringer & Milkovich, 1998). As a single theory seldom provides a comprehensive explanation, various combinations of theories – institutional, transaction cost, resource dependence, agency, population ecology, and/or contingency – have been adopted by innovation researchers. These theories help to explore the factors affecting management's decisions over the adoption of the innovative water-loss management. Because a few water utilities have adopted proactive water-loss management, it is helpful to examine these in depth. Thus, this study conducts case studies with survey questionnaires, based on integrated theoretic perspectives.

Beyond technical guidelines for water-loss control, there are a few studies on water-loss management that identify the influential factors related to water losses (Cummings et al., 2004), and other studies quantify the water losses (Wallace, 1987; Hyman, 1998; Laughlin, 2001; Kunkel, 2002; Lambert, 2002), while others evaluate the performance of water-loss management (Moyer, Male, Moore, & Hock, 2002; Brown, 2002; Sullivan& Speranza, 2002; Counts, 2002). Previous research was based on anecdotal case studies and did not attempt to identify the water loss problems in the whole U.S. framework, which calls for a comprehensive analysis of water losses.

The goal of this study is to help policymakers and water utilities develop strategies that proactively solve water losses. To develop strategies for water-loss management, it is essential to identify key factors that determine the level of water losses as well as the factors that encourage the adoption of the innovative control practices. Using three different datasets[9] and statistical methodology, this study analyzes the factors that are likely to be associated with water losses and utilities' responses to the problems.

This study is designed to answer the following two questions: (1) What factors determine the level of water losses; (2) what factors affect management's decisions over the adoption of the proactive water-loss management? This study is organized in the following way. Chapter 2 provides a literature review and Chapter 3 outlines the methodology of the study. Chapter 4 analyzes the factors that determine the level of water losses, based on results of data analyses. Chapter 5 explores important factors associated with the adoption of proactive water-loss management through the analysis of some case studies. Finally, Chapter 6 discusses the policy implications of this research and concludes with recommendations, a discussion of limitations, and suggestions for further research.

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[9] As stated above, data on water losses is limited, and no single dataset seems comprehensive. Hence, to get more reliable answers to the research questions, this study analyzes three different datasets in different models: the AWWA dataset, the Raftelis Financial Consulting (RFC) dataset, and the EPA dataset.

CHAPTER 2

LITERATURE REVIEW

This chapter begins with a conceptual framework in which the definitions for important terms in this study are provided. This chapter includes a literature review that suggests the possible variables that can determine the level of water losses. A brief review of a different strand of research identifies factors related to the adoption of innovations.

Definitions: Conceptual Framework

To develop a strategy for controlling water losses, it is necessary to define water losses and identify the potential water for recovering. Several expressions represent the term of water losses, such as “unaccounted-for water (UFW),” “total water loss,” “non-revenue water (NRW),” “non-account water (NAW),” “unauthorized water uses,” and ‘”water leaks.” Understandably, the lack of a standardized definition has been criticized (Wallace, 1987; AWWA Water Loss Control Committee, 2003).

The following diagram (Figure 1) illustrates the division of “total water produced” into its various components and the two policy parameters that manage water losses: restoring rate (α) and identifying rate (β). Total water produced incorporates water purchased as well as that produced by a water utility and should be adjusted for known errors such as system input metering errors[10]. Non-revenue water (NRW) can be calculated by subtracting billed water consumption (revenue water) from total water

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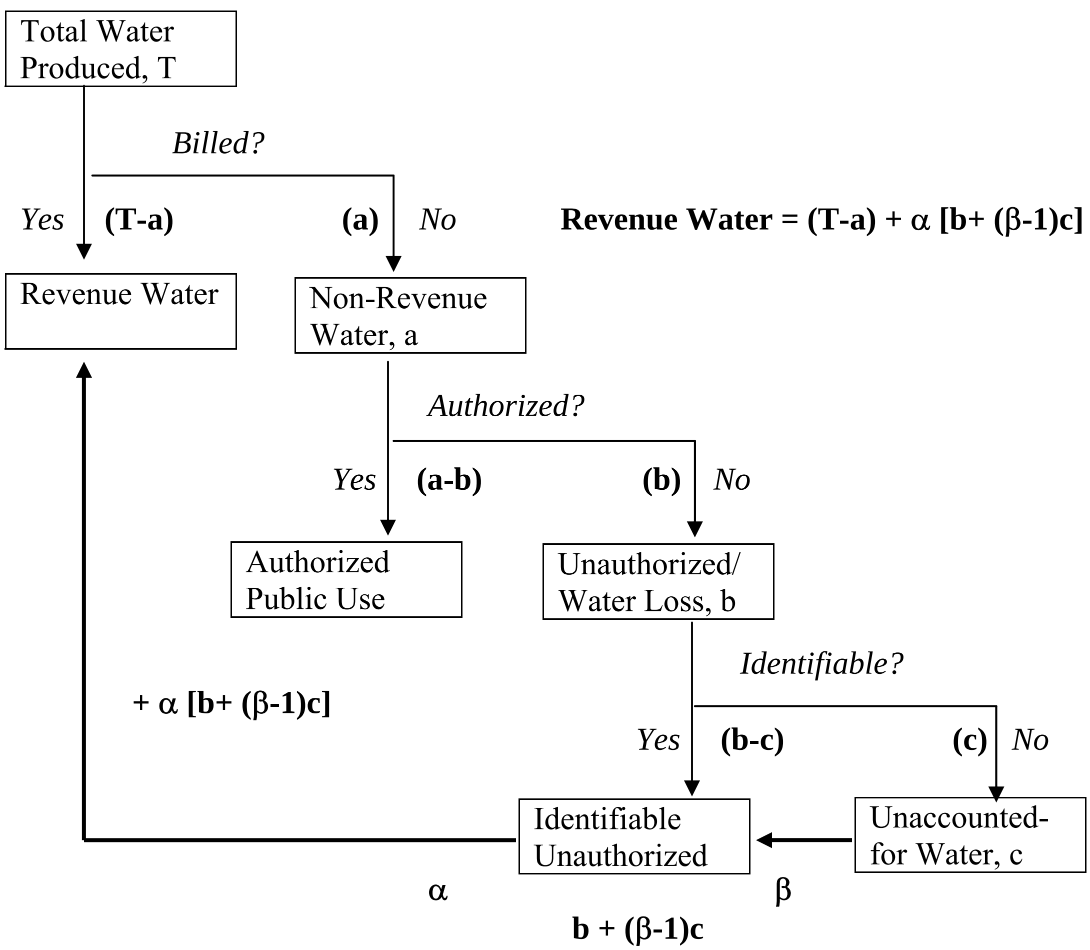
[10] According to Cummings et al. (2004), meter measurements can be subject to a variety of errors.

produced. “Authorized Public Use” provides for public water uses such as fire fighting, street cleaning, and other public uses that are not usually billed or even metered, so it is hard to distinguish unauthorized water loss from authorized public uses. As a result, water use databases of USGS and EPA combine these concepts into one category.



T: Quantity of Total Water Produced
a: Quantity of Non-Revenue Water
b: Quantity of Water Loss
c: Quantity of Unaccounted-for Water
α: Restoring rate of Water Loss
β: Identifying rate of Water Loss

Figure1. Conceptual Framework

Given the difficulties in distinguishing between authorized and unauthorized uses, NRW can be used to approximate water losses that are of interest to many water utilities.[11] However, as NRW and "total water loss" involve separate issues and call for different strategies, this study uses "total water loss" to estimate the level of water losses, except when a dataset provides only NRW.[12]

For water utilities, unauthorized uses represent total water loss calculated by subtracting the sum of revenue water and authorized public uses from total water produced. Total water loss consists of identifiable unauthorized uses and unaccounted-for-water (UFW). Even though there is strong argument that the concept of UFW should not be used in the water industry because it is less consistent and comparable[13], the U.S. EPA and the water industry are familiar with the term of "UFW."[14]

A lack of knowledge about the amount of water lost and the causes of such losses is counter-productive for water suppliers. Even though tracking their product and inspecting underground infra-systems is not an easy or inexpensive task, water utilities are required to identify where the losses exist and how much the losses represent. The International Water Association (IWA) has recommended a new international standard water balance without using the term of "UFW," assuming that all components of the water balance should be accounted for. To follow the IWA water balance, a water utility

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[11] Dr. Cummings and his colleagues (2004) used "NRW" or "NAW" to approximate the potential magnitude of avoidable water losses in Georgia's municipal water supply systems.
[12] The EPA dataset provides the amount of water delivered to the category of 'system losses & uncompensated usage,' which is more likely to mean "NRW" than "total water loss" or "UFW."
[13] The AWWA Committee argues that the water industry should not use the term of "UFW," based on a doctrine – "all water is accounted for as either a consumptive use or a loss (AWWA Committee, 2003, p69)," and many researchers support the doctrine (IWA, 2000; and Wallace, 1987).
[14] Still, many water utilities use the term of "UFW" in their water balance and Nickson and Franceys (2003) imply that the UFW ratio is one of the most common indicators of operational efficiency.

should set the target of the identifying rate of water loss (β) at 100%, which is attainable when it implements proactive water-loss management practices including thorough metering, system audits, error tests such as billing/account test, and leak detection programs. An identifying rate of water loss (β) is the ratio of newly identified unauthorized water uses to UFW.

After identifying unauthorized consumption, a water utility can reduce water losses by restoring identifiable unauthorized consumption to revenue water.[15] The restoring rate of water loss (α) indicates the relative amount of the unauthorized consumption restored to revenue water among the identifiable water losses. The restoring rate (α) can be increased when a water utility implements active repair programs, meter installation/ upgrades, accurate billing/account systems, illegal-use control, and pressure control practices. Passive leak repair programs can also increase the restoring rate (α), but it may not have as great as impact as the proactive approach.[16] That is, proactive water-loss management will decrease water losses more effectively by increasing both the identifying rate (β) and the restoring rate (α) together. Without increasing the

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[15] In fact, restored water is converted to both revenue water and non-revenue water, and it is hard to quantify how much water is directly restored to revenue water. However, the amount of water restored to revenue water must be much greater than that to non-revenue water even though some portion of restored water is going to some other uses rather than revenue water, which saves the same portion of total water produced. That is, restored water will increase revenue directly or indirectly, so this study assumes that all of the restored water is going to revenue water as shown in Figure 1.

[16] Passive leak control is unlikely to affect the identifying rate (β) but it is likely to influence the restoring rate (α) even though its influence on α seems smaller than the influence of proactive programs. The passive approach will increase revenue water by $\alpha*(b - c)$. Because water utilities keep repairing visible and reported leaks and breaks, the passive approach continues to be a part of water-loss control programs regardless of the existence of a proactive approach, so it is difficult to differentiate the respective effects of proactive programs on the restoring rate from those of passive leak control. However, proactive water-loss management will decrease the degree of the impact of passive programs on the restoring rate by reducing unexpected breaks and leaks.

quantity of total water produced, revenue water will be increased by α*[b + (β-1)*c] through proactive water-loss management that boosts all the policy parameters together - α and β; the following equation identifies the potential water for recovering.

Revenue Water = (T-a) + α*[b + (β-1)*c]

In accordance with the causes of losses, the IWA classifies total water loss into two groups: real losses resulting from leakage related to poor infrastructure and operational practices; and apparent losses resulting from illegal connections, accounting errors, and meter inaccuracy. The distinction between real and apparent losses is important not only when utilities or policymakers develop appropriate strategies, but also when they identify the different financial impacts of two types of losses.[17] The IWA approach for water losses seems to be straightforward and useful. Unfortunately, many U.S. water utilities are unfamiliar with these terms and no reliable data exist that identify the amount of real losses and apparent losses.[18]

Sometimes, the term of “water leak” is confused with “water loss,” but the latter is a much broader concept than the former that is only related to real losses. Even though leakage is a major cause of water losses, proactive water-loss management does not simply depend on technical practices to control system leaks but instead requires a comprehensive approach to reducing any waste and losses and improving the efficiency

[17] AWWA Water Loss Control Committee (2003) maintains that on a short-term basis, apparent losses are more costly than real losses because apparent losses are valued at a retail sale price whereas real losses are valued at marginal production costs. The committee also argues that controlling apparent losses can yield a speedy payback and it requires few resources.

[18] Several water utilities have made efforts to follow the IWA water balance (Thornton, 2002-a), and a 2002 survey conducted by the AWWA tried to identify the differences between real losses and apparent losses and found that 71.7 % of water losses in the 251 sample water utilities were related to real losses (Kunkel, 2003). However, this number did not seem objective or reliable because the answers were based on guesses by respondents not on the results of their water balance.

of the whole system. Water distribution systems usually allow a certain amount of water leakage in accordance with system pressure, pipe size and type, and joint number and type, which is not often economical to repair (Wallace, 1987). Thus, unavoidable leakage and economic level of leakage (ELL)[19] can be differentiated.

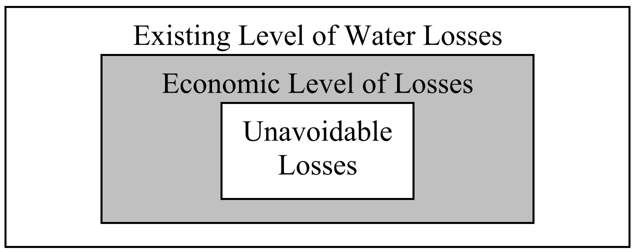

Figure 2. Different Levels of Water Losses (source: Thornton, 2002-a)

Figure 2 shows the different levels of water losses. The meaningful target for water losses is the economic level.[20] This economic level is not static, but can change, depending on technical improvements, water prices, and other factors. For example, as technologies to control water losses improve and the costs and the risks of adopting the technologies decline, the efforts to control water losses can be more feasible. In addition, the efforts to save water when water becomes expensive are more justified than those

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[19] According to the AWWA Water Loss Control Committee (2003), ELL can be defined as the leakage level at which the costs and benefits of leakage control become identical.

[20] It seems possible the "economic level" is actually above the "existing level," which means that water utilities control water losses inefficiently. Even though current technology may allow reaching to the level of unavoidable losses, it is not economically desirable to make the existing level below the economic level.

when water is cheap. As water rates continue to increase[21], the portion of water losses that is economical to mitigate also appears to increase.

To develop strategies for reaching the goal of the economic level of losses, it is vital to estimate both the existing level and the economical level. Several standardized methodologies are available to calculate them[22], but only a few water utilities use them to make such calculations. According to the AWWA Committee (2003), most American water utilities do not regularly implement formal water audits, so that they are not sure how much water has been lost. Laughlin (2001) argues that most U.S. water utilities are unfamiliar with standardized accounting methodologies and concepts for water usage. Given the difficulties in obtaining extensive data to estimate water losses in different categories, this study focuses on "total water loss" but when the data are not available, NRW is substituted for it.

Studies on Water Losses

Although the water industry has conducted many studies on the important problem of water losses, there is no comprehensive theory to explain water losses. Thus, the purpose of this section is to understand the developments of research on water losses and to identify the potential factors associated with water losses.

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[21] Based on a survey of water systems serving a total of 167 U.S. cities and counties, six Canadian cities, and 8 international cities, the RFC (2002) found that the water rate increased 4.3% annually from 2000 to 2002, which is higher than the increase of the Consumer Price Index during the same period.
[22] Refer to Thornton (2002-a)

Developments of Research on Water Losses

As a result of increased concern about water losses, a variety of technical guidelines and technical reports describe the procedures and methodologies for detecting and repairing leaks. Guidelines for analyzing the feasibility of technology renovation have also been formulated. The AWWA has published several manuals to help utility operators detect and repair leaks, conduct a water audit, and establish a plan for water-loss control.[23] The AWWA Research Foundation (AWWARF) has also funded several studies such as "A Study of Leakage Management Technologies," the purpose of which is to develop efficient ways to apply leakage control technologies to the U.S. water industry. The IWA, in several journals, has provided a variety of information and technical guidelines to control water losses. From 2003 to 2004, the IWA Water Loss Task Force developed and promoted a number of practical approaches to water-loss reduction including non-revenue estimation, pressure management as a control tool of leakage, leak detection techniques, District Metered Area (DMA) practices, real-loss assessment, and an apparent water-loss control methodology[24]. Other organizations including the World Bank and the European Investment Bank have also recognized the seriousness of water losses and the importance of water-loss control and have made efforts to develop technology and guidelines to share information.[25]

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[23] For example, Water Audits and Leak Detection (M36), 2nd ed., 1999; Water Supply Operations – Water Loss Control, 2004; On-the-Job – Leak Detection, 2001; and Preparing for Water Main Breaks, 1997.
[24] Refer to the following journals: Water 21, Water Science and Technology: Water Supply, Water Intelligence Online, AQUA, and The Blue Pages.
[25] One example of the international efforts: in 2002, an international conference on leak management was held in Cyprus and helped boost up worldwide concern about the issue of water losses.

According to an international report titled "Water demand management and conservation including water losses control" (2000), the international community seems to be giving serious attention to water losses, and the extent of control of water losses varies from country to country. Lambert (2002) called for a standardized international approach to water losses by presenting the international state-of-the art water-loss management. This issue has been dealt with in research worldwide: the magnitude of water losses was estimated in Saudi Arabia; Al-Ghamdi and Gutub (2002) investigated water leakage in Makkah; Nguyen (2004) attempted to improve accuracy in the water loss estimation in Paris; Mimi, Abuhalaweh, Wakileh, and Jerusalem Water Undertaking Staff (2004) presented a way of evaluating and controlling water leakage based on a case of one city of Palestine; Montenegro, dos Santos Neto, Onoyama, and Thome (2000) described a success story of controlling water losses in Brasilia; Chowdhury, Ahmed, & Gaffar, (2002) estimated water system leakage in four cities of Bangladesh and provided some methodologies and approaches to reduce water losses.

The United Kingdom (U.K.) has played a leading role across the world in developing water-loss management since 1995 when controlling water leakage was recognized as a strategy to deal with severe drought. As a result of research, the National Leakage Initiative, the Office of Water Services (OFWAT), and the Environment Agency have forced[26] the water industry to reduce leakage and encouraged it to invest in leakage-control technology. In addition to the development of technology, systematic processes for leakage, including leakage target setting, methods of calculating the economic level of

[26] Water industry in the U.K. has a statutory duty to promote the efficiency of water use including the reduction of water leakage.

leakage, leakage performance indicators, and analytical tools for understanding the financial, social, and environmental impacts of leakage, have been established. These efforts have proven successful, reducing water leakage by 30 percent.[27]

As technology and practices for water-loss management have developed and international attention to water losses has grown, the problems of water losses in U.S. water utilities have come to the forefront. The results of a comprehensive survey conducted by Beecher (2002) analyzed the level of the utilization of water-loss reporting requirements and guidelines for drinking water utilities by state and regional water agencies. Although numerous water agencies address the issue of water losses, only a few agencies seem to provide instructions or enforce rules consistently. Several attempts to quantify the amount of water losses across the U.S. have been made (Wallace, 1987; Hyman, 1998; Laughlin, 2001; Kunkel, 2002; Lambert, 2002) and the AWWA conducted two nationwide surveys to better understand the current conditions of water losses. Because most U.S. water utilities have not established a consistent data collection system of water losses, the information may not be consistent or reliable. However, the AWWA datasets include state-wide extensive information, so the datasets have been utilized for this study.

Maloney et al. (1986) showed that the benefit to cost (B/C) ratio derived from some early leak detection programs was greater than 1, emphasizing their cost-effectiveness. Thornton (2002-a) introduced several case studies showing the efficiency of water-loss management. Even though the costs and benefits of the case studies did not

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[27] According to OFWAT 2002-2003 Report, England and Wales have lowered leakage from 4980 Ml/d (mega-liters per day) to 3623 Ml/d since 1995.

appear to be based on solid scientific analysis[28], all cases reached the same conclusion: that is, water-loss management is beneficial to water utilities. On average, Lahlou (2001) insists that the savings from water-loss control outweigh costs. Cummings et al. (2004) also argue that leak detection/repair programs would be cost-effective, based on several assumptions and simple calculations. However, it is unclear if water-loss management is always efficient because costs and benefits can be different according to the conditions of the water industry, the economy, the environment, and society. However, as situations of water scarcity are worsening, the efficiency of water-loss management should be proven in more cases.

Factors Associated with Water Losses

Despite the myriad theories and studies that explain and predict organizational performance, few deal directly with the issue of how water utilities perform with regard to their water loss problems. Therefore, an assessment of the current operational performance of water utilities should be undertaken. Performance can assessed in numerous methods, but comprehensive and comparable analyses can be conducted when generalized indicators are utilized. The IWA has proposed a set of performance indicators (PI)[29] for water-loss control that allows performance comparisons and benchmarking, and several researchers have attempted to improve the PI which covers all organizational

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[28] Most case studies simply compared the costs of purchasing and operating equipment with the benefits calculated from saved water. The studies failed to consider other possible costs and benefits such as avoided costs and long-term effects of water-loss management.
[29] Refer to Alegre, H., Hirner, W., Baptista, J.M. & Parena, R. (2006) and IWA (2000).

functions, through some pilot studies[30]. Although a number of water utilities fail to operate at full efficiency (Saleth and Dinar, 2004), efficiency is one of the most important issues for water industry. Several PIs represent efficiency or inefficiency such as the amount of water produced or delivered per employee, the most important indicator of operational efficiency; the cost coverage ratios (total revenues/ total costs or operational costs), key indicators of financial efficiency; or water losses per mile or connection, a typical indicator of system inefficiency. Operational, financial, and system efficiency are likely to be related; and this study tests the relationship among these efficiency indicators.

Until recently, several indicators such as the "metered water ratio" and other percentage indicators have been used to measure the performance of water utilities.[31] There is some controversy over the usefulness of these percentage indicators. The percentages do not provide any direct information about volume and cost, nor do they consider various levels of consumption.[32] Thus, the international water audit methodology suggested by the IWA recommends that water industry use units of volume to present all uses and losses. Water losses expressed as a percentage might not be useful to identify the relationship with system characteristics or other factors. Based on a survey of Georgia public water supply systems, Cummings et al. (2004) found that water losses expressed as a percentage were related to population served but not to other system characteristics such as the number of employees, the source of the water supply, the

[30] Carpenter et al. (2003) and Margues and Monteiro (2003) explored the PI systems by applying them in Australia and Portugal, respectively.
[31] According to Nickson and Franceys (2003), one of the most common indicators of operational efficiency is the UFW ratio which is calculated from the difference between the volume of water delivered to the distribution system and the volume of water actually sold, and expressed as a percentage of net water production delivered.
[32] Thornton (2002-a)

quantity of water pumped from a source, the age of infrastructures, and the base charge for water. From the perspective of a water utility, however, water-loss percentage is an important benchmark of system inefficiency; thus, this study considers water losses expressed as a percentage as well measured in volume terms.

Even though most studies focus on leakage detection and repair, some research explores operating practices affecting water losses, such as system pressure and flow rates. Systems must be operated at an appropriate pressure to prevent inward flow into pipes and at the same time, manage outward leakage. The water industry seems to set system pressure based on both public health and safety and operational purposes rather than on loss control. However, as the critical link between energy losses and water losses has been more apparent[33], the control of system pressure has been focused as a strategy for reducing energy and water losses[34].

A statistical analysis by Mueller (2001) indicated that metering has a substantial impact on water conservation. As metering is also an elementary step in determining water uses and losses and developing improvement plans, a comprehensive and reliable metering system is always included in water-loss control strategies. According to Arregui (2006), large meter replacements increased registration and revenue by dropping the level

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[33] Colombo and Karney (2003) analyzed the negative influence of leaks on energy and water consumption, based on the effect of leaks to reduce pressure in distribution networks; the Federal Energy Management Program (FEMP) of the US Department of Energy recognizes the need for water efficiency including water loss control in energy management; and a report of "Energy Down the Drain" by Cohen et al. (2004) suggested the integration of energy use into water planning to reduce waste and save money. According to Hyman (1998), because of expensive pumping systems, distribution costs account for 65% of total operation costs, so the reduction of energy costs, which can be accomplished by minimizing leakage and keeping appropriate pressure, is very important to every water utility.

[34] According to Thornton (2002-b), pressure management has been applied for the reduction of leakage. Several case studies have showed successful implementation.

of apparent losses. The water industry database (WIDB) of the AWWA (1992), which accounts for about 2% of the total 59,000 community water systems and represents 50% of the total 226 million people served, showed that 94% of the 29 million service connections were metered. Even though the metering level of the U.S. water systems is relatively high, meter inaccuracy can still lead to the water loss problems[35]. Thus, meter conditions, as well as metering rates, are likely to affect water losses.

Mueller's research (2001) tested the impact of customer mix on per-capita water production and found that it was not statistically significant in California. That is, the amount of water produced was unlikely to be associated with the mix of customers– residential, commercial, industrial, institutional, irrigation, and others. However, the different ratios of residential customers to nonresidential customers can also be associated with system characteristics such as pipe size, which may affect the level of water losses.

Corral (1997) argued that pricing could also be an effective policy tool in encouraging water conservation, criticizing the negative impact of inappropriate pricing systems on conservation. Extensive research supports the benefits of conservation-oriented rate structures such as increasing block rates or seasonal rates (Clunie, 2004; Khawam, 2004; and Wang, Smith, & Byrne, 2005). Despite the absence of studies about the relationship between the level of water losses and the type of pricing system, the conservation-oriented pricing system is likely to decrease water losses when a utility implements comprehensive conservation programs since conservation-oriented rates and

[35] According to the AWWA 2002 distribution dataset, 95% of the 328 U.S. water utilities reported that they had inaccurate input meters, and over 35% reported errors in customer metering systems.

water-loss management as well as public information and education are all basic conservation practices[36]. That is, the relationship between water losses and other conservation practices seems apparent.

Although water services are considered a vital public service and thus any increases in water rates have political and legal ramification in the United States, water prices continue to rise, leading to a growing concern about rate shock[37]. This trend is expected to change not only the behaviors of customers, but also the response of providers to water losses. When utilities plan to increase water rates, they are required in most cases by law to justify their plans and gain approval from a public board, a utilities commission, or other decision-makers. It would be hard to obtain approvals for rate increases if the level of water losses in their systems was high. Thus, the amount of water losses is likely to decrease as water rates increase.

In water industry, size is expressed as the number of people served[38], and size is often an excellent determinant for performance of a water utility including the level of water losses. Hawley (2000) examined the influence of size (i.e., customer base) on water-industry performance and found that the size of the utility influenced only one measure of pricing along with staffing. Dr. Cummings and his colleagues found a positive relationship between the size of the population served and the level of water losses as a percent of total system supply. The variable of size is likely to be directly

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[36] A new guidance manual for water conservation developed by the AWWA includes the reduction of water losses as one of the key elements in conservation (AWWA, 2006).
[37] According to the AWWA (2004), many water utilities were expecting over a 10 % increase annually.
[38] The EPA has categorized the sizes of US water utilities, based on average daily population served, and suggested the following five categories of water system size: a) Very small=25-500; b) Small=501-3,300; c) Medium=3,301-10,000; d) Large=10,001-100,000; e) Very large=>100,000.

associated with water losses. However, Hall (1972) argued that size could affect organization behaviors in a variety of ways, so it could not be taken as a simple predictor as it often was. In fact, the size of the population served is likely to be strongly related to the total water produced, costs, revenues, the number of employees, the number of connections, and the length of distribution systems, all of which can represent the size of a system. Hence, there is considerable difficulty in distinguishing different effects of the size-related variables on water losses.

Garcia and Thomas (2003) examined the impact of asymmetric information on water losses. When the information available to both a public regulator and a private water supplier was asymmetric, they found that water losses were likely to be more prevalent. A study by Aubert and Reynaud (2005) showed that utilities seemed more efficient under a rate of return regime where the Wisconsin state regulators collected extensive information. Anwandter (2000) argued that new changes could have a positive effect on the efficiency of water utilities when the changes reduced information asymmetry between the managers of the water utilities and the local users or regulators. Water suppliers and public regulators do not seem to share the same level of information.[39] According to Beecher (2002), only 20 states among the 43 states surveyed in her research required utilities to implement water accounting and reporting, which may be one possible explanation for the high level of water losses observed in the U.S. water systems. So, water losses are likely to be smaller when information on water losses is disclosed to regulators and the public.

[39] Kaplan (2005) argues that the public and policymakers are not well informed about utility operations.

Extreme weather conditions affect the operation of distribution systems by causing more water line bursts and breaks. Dry weather impairs the availability of water resources, which triggers efforts to improve the efficient use of water, so numerous case studies and research on water conservation often take place in the dry western states (Talarowski, 1982; Rubinstein, 1982; Abdallah, 1985; Trauth, 1989; Corral, 1997; and Mueller, 2001). That is, weather is likely to be one of the factors that influence the level of water losses or the level of the efforts at controlling the losses. In addition to weather, growing populations and growing economies also place pressure on water resources by increasing demand. Even though the relationship between income and water uses is not evident (Gracia et al., 2001), according to Chicoine and Ramamurthy (1986), customers with higher household income are less sensitive to their water bills, which could result in more water consumption. So, similar to population growth, income can be used to estimate water demand. Since many areas are suffering from water shortage, the increasing demand are likely to call for both demand-side and supply-side conservation.

According to Hutson and his colleagues (2005), surface water has been the primary source of water during a 50-year period but the percentage of groundwater withdrawn for public supply has increased from 26% to 40%. As public-supply withdrawals have been increased by more than 200%[40], most surface water has already been developed. The current capacity of surface water available as new water sources appears to be insufficient. According to Jordan (1998), only 9% of river miles in the lower forty-eight states remain undeveloped. Generally, groundwater is more economical

[40] Hutson et al. (2005)

owing to low treatment costs. However, as low-cost, high-quality groundwater resources are depleted in some areas, groundwater becomes a costly resource due to increased pumping costs and treatment requirements.

Utilities utilize the different types of water sources according to different factors, such as geographical, hydro-geologic, engineering, and contamination factors (Campbell, Michael D. & Campbell, M. David). Because of diverse situations, it is hard to identify the relationship between the type of water source and the level of water losses. However, if a utility uses groundwater as a primary source, it may shift a water source from surface water to groundwater because surface water has been a traditional primary source, so newly-developed groundwater may be more subject to water shortages or efficiency, which can influence the response of utilities to water losses. Moreover, some water utilities purchase treated or untreated water from other utilities when no water resources are available or when the developing costs of new water sources are too high. Such a situation is likely to result in less water losses.

In the 21st century, the water industry in the United States must attempt to improve performance as it faces a variety of challenges, such as growing service demands, an aging infrastructure, more stringent standards and regulations, higher customer expectations, and system security maintenance (Seidenstat, 2005). A utility with effective performance in some fields is more likely to have effective performance in other fields. For example, a water utility that established a strong reputation for customer service is unlikely to experience substantial water losses. Water quality is one of the most important issues to water utilities, especially, ones that provide drinking water for customers. Water utilities that attempt to improve water quality may make an effort to reduce water losses. That is, efforts to improve water quality and system efficiency are likely to be related.

Not surprisingly, water utilities that implement proactive water-loss management can expect to reduce water losses. Damanpour and Evan (1984) tested the relationship between innovations and performance and confirmed that high-performance organizations were more likely to adopt innovations than low-performance organizations. That is, water losses and innovation seem to have an inverse relationship. Thus, identifying the potential factors that determine water losses starts with the identification of the key organizational characteristics and other variables that encourage the adoption of innovations. A following section of this chapter discusses this issue by exploring theoretical explanations for the adoption of proactive water-loss management.

It is difficult to identify the organizational characteristics related to water losses. For example, the number of employees could contribute to increased or decreased water losses because it is not only a size-related factor but also a vital resource to manage water losses. Also other organizational characteristics such as leadership or structure are often difficult to measure. However, since organizational characteristics are directly related to performance, they will affect the level of water losses. So, this study will test the relationship between water losses and a measurable organizational characteristic – the number of employees.

Infrastructure condition must be one of the most important factors to determine water losses. The American Society of Civil Engineers (ASCE) evaluates that the nation's water infrastructure as very poor (a D grade) and investment in infrastructure rehabilitation or extension falls short by $11 billion every year.[41] Lary (2000) estimated that 250,000 main breaks occurred in the American water infrastructure in an average year, which cost more than $1 billion a year. Thus, the greater extent of infrastructure rehabilitation is related with the lower level of water losses.

Utilities with a high level of water losses in the systems may recognize the seriousness of the problem and they may either take actions to reduce it or they may take it for granted and take little or no action to improve infrastructure conditions. That is, it is not clear whether water-loss history impacts the level of the current water losses positively or negatively. However, regardless of the sign of the influence, the current level of water losses is affected by water-loss history.

AWWARF (2005) called attention to the failure of large-diameter water pipes because they can cause bigger water-loss disasters. In other words, the size of a pipe can affect water losses in very different ways. In addition, as pipes become older, the failure rates of pipes are expected to go up because aging pipe is subject to get breakage and subsequent water losses. Thus, older pipelines contribute more to water losses than younger pipelines.

Pipe sizes and length are likely to be related to service density. Alegre and his colleagues (2006) suggested two different operational water losses performance indicators: one expressed in terms of water losses per connection is for systems with high service density and the other expressed in terms of water losses per pipe length is for

[41] Refer to Water World Online Article: "AWWA: water infrastructure requires new approach to make the grade."

systems with bulk supply and low service density. They found that the number of connections could be a very important factor in a highly-populated area while the length of pipe lines could be more important in a less-populated area. That is, service density, which correlates with system size variables such as connections and pipe length, is likely to increase water losses.

Efforts to reduce water losses often require substantial investment, so the financial situation of a utility plays an important role in determining the level of water losses. Utilities with insufficient financial resources might not focus on water loss issues as these might not be a priority to them. For example, when a utility is carrying a high level of debt or liabilities, it is hard to invest extra funds to mitigate water losses, while a utility with sufficient assets and revenues is likely to invest to reduce water losses. Therefore, the evaluation of the ability of a utility to address water losses would involve a decomposition of costs, funding sources, and total fiscal condition.

Even though no studies discuss direct institutional influences on water losses, Aubert and Reynaud (2005) showed that regulation might have a positive impact on the efficiency of water utilities; this highlights the importance of institutional pressure in managing water losses. According to a survey by Beecher (2002), no clear institutional incentives and penalties had been established for water-loss management in the United States. However, the states are establishing various institutional frameworks with different levels of pressure and requirement, which may affect the responses of utilities to water losses.

While the water industry in the United Kingdom has improved its efficiency through privatization, the water industry in the United States is still dominated[42] by public ownership (Lauer & AWWA, 2001). Milgrom and Robers (1992) argued that "ownership is the most common effective means to motivate people to create, maintain, and improve assets" (p321). Theoretical arguments over the relationship between ownership and performance usually draw on the property rights approach, the public choice theory, and principal-agent model or the theory of regulated utilities (Renzetti & Dupont, 2003; Byrnes, 1986).

Based on empirical results, Byrnes (1986) asserted that publicly-owned and privately-owned water utilities were different in the degree of their efficiency because of significant differences in their technologies or operating environments. Onyeji (2000) found that the private water utilities in the United States were more technically efficient than the public water utilities, and that the risk of incurring losses in public water utilities was higher than that in private water utilities. He also showed that most performance indicators responded more sensitively in public water utilities. Crain and Zardkoohi (1978) also argued that publicly-owned water utilities in the U.S. operated less efficiently than privately-owned utilities. However, according to Anwandter (2000), the low efficiency of public water utilities could be explained by other factors than the type of ownership such as the monopolistic market structure, principal-agent problems, and the distorting effects of regulation.

[42] About 85% of the U.S. population is served by publicly-owned systems

Byrnes (1986), Estache & Rossi (2002), Fox & Hofler (1986) and Morgan & Chapman (1996) argued that ownership did not significantly affect efficiency. Hawley (2000) revealed that type of ownership had only minimal influence on pricing systems, infrastructure investment, and additional services. According to Agthe (2003), the operations of private water utilities in the U.S. did not seem to differ significantly from those of public utilities because regardless of system ownership, they are administered by state public utility commissions and subject to regulations more than market situations, which might explain why the impact of ownership is unclear. However, Byrnes (1986) argued that the lack of consensus about the relationship between performance and ownership type might be the result of the data and specification problems inherent in the methodologies. Although the results of research about the impact of ownership on efficiency lack consensus, it is reasonable to conjecture that water losses will be less in privately-owned utilities because private utilities will be concerned with profits. Thus, revenue losses resulting from water losses will be a concern, which could lead to more active strategies to deal with water losses.

Summary of a Model of Water Losses

This section summarizes the potential factors associated with water losses. Rather than simply listing the factors, a categorization might provide a clear way to summarize them.

Table 1. Factors Associated with Water Losses

Factors	Direction of Influence[43]
O&M	
1. System size (production, length of line, & population)	+
2. Infrastructure rehabilitation	-
3. Pipe size	+/-
4. System age	+
5. Density	+
6. System pressure	+
7. Costs (operation, & maintenance)	-
8. Operational efficiency	-
9. Water quality	-
10. Water-loss history	+/-
Internal	
1. Customer mix	+/-
2. Customer relations	-
3. Innovative organizational culture	-
4. Organizational structure (# of employees)	+/-
5. Metering rate and accuracy	-
6. Water conservation	-
7. Cost coverage	-
8. Water rate	-
9. Capital investment	+/-
10. Debt	+
11. Funding size and type	+/-
External	
1. Private ownership	-
2. Supply constraints	-
3. Type of water source	+/-
4. Water demand	-
5. Information asymmetry	+
6. Institutional pressure	-

As water losses are directly affected by conditions, efficiency, costs, sizes, and other performance indicators of operation and maintenance (O&M), the O&M is the most important category that accounts for water losses. The category includes a variety of

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[43] "+" means an increase in water losses and "-" means a decrease in water losses.

O&M factors, such as infrastructure conditions, operational efficiency[44], production costs, operation costs, total water produced, system pressure, and water quality. All other factors can be categorized into either internal or external factors. Utilities may have more control power over the internal factors, such as customer relations, organizational structure, and strategic management than the external factors such as water demand, water resources, and institutional limitations. Table 1 provides a list of the factors by category and shows the potential direction of influence of each factor.

Theoretical Explanations on the Adoption of Proactive Water-Loss Management

Rational organizations tend to improve their performance by adopting innovations, a topic of interest to organization researchers (Damanpour, 1987). Damnpour claims that no reliable and comprehensive innovation theory has been developed, but the topic of innovations is popular to researchers and organizations that desire to take advantage of innovations. Thus, many studies have focused on innovations in private sectors (Barringer and Milkovich, 1998) but concerns about innovations in public sector are growing (Kelman, 2005; Borins, 1998; Altshuler & Behn, 1997; Levin & Sanger, 1994; Danziger & Dutton, 1977).

Saleth and Dinar (1999) agued that the water sector must ensure financial self-sufficiency and adopt innovative technology and information inputs to minimize the transaction cost and maximize the performance impact. Seindenstat (2005) also emphasizes the importance of innovations, presenting several cases of innovations

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[44] Efficiency in this study means "the amount of water produced or delivered per employee," the most important indicator of operational efficiency unless explained differently.

implemented by U.S. public water utilities. However, no theoretical studies explain the factors that encourage the water industry to adopt and implement innovations, so this study identifies the factors that affect management decisions related to the adoption of proactive water-loss management by extrapolating from research on the adoption of innovations in other sectors.

Internal Factors: Organizational Factors

A great deal of research based on case studies has identified a myriad of factors that may influence the adoption of innovations. Even though researchers have not specified key factors, many of them claim that organizational factors are very important (Baldridge & Burnham, 1975; Kim, 2002; Kimberly & Evanisko, 1981; Mohr, 1969). Kimberly & Evanisko (1981) maintained that size, a basic characteristic, was the most important predictors of innovation and Mohr (1969) also affirmed that organizational size was an excellent indicator for innovation. Baldridge & Burnham (1975) found that structural characteristics of an organization – size, heterogeneity, and structural complexity – were important variable in the adoption of innovations. Kim (2002) found that organizational innovation was positively correlated with professional training, professional activity, and integration, and negatively correlated with job codification and hierarchy of authority.

Damanpour (1987) listed six organizational variables that might affect management's decisions on innovations: specialization, functional differentiation, professionalism, size, slack resources, and administrative intensity. While Danziger and Dutton (1977) found little evidence that internal slack financial resources and top management support were related to successful adoption of innovations, other studies confirmed the important roles of leadership, support, and coordination provided by managers (Hall, 1972). Kelman (2005) emphasized the critical role of leadership in initiating change, arguing that leaders were able to coordinate political struggles between supporters and critics inside the organization. Hage & Dewar (1973) emphasized the relative power of leadership in predicting innovation and the usefulness of the concept of "elite values". A study by Goodstein and Boeker (1991) found that the changes in leaders and board members significantly influenced changes in the organization.

However, leadership stems from not only top management but also middle management. According to Borins (1998), front-line and middle management public servants were more likely to initiate innovations in public sectors than agency heads. Grady (1992) also emphasized the central role of middle-level managers in promoting innovations in the public sector. Resource dependence theory claims that agents who control critical resources influence organizational structure and decisions, supporting the important role of managers in innovation adoption. However, the extent to which management decisions are passive versus active was likely to be determined by organizational characteristics (Barringer & Milkovich, 1998). Hall (1972) suggested careful generalization of research results, arguing that the studies on leadership were highly contextual to specific situations. Also, Barringer and Milkovich (1998) maintained that external as well as internal agents may hinder decisions to innovate.

According to several researchers, a crisis, which can originate either internally or externally, can induce innovations (Borins, 1998; Downs, 1976). According to Osborne and Gaebler (1992), fiscal crisis is the most common form of crisis in the government. Since most water utilities across the United States have the problems of an aging water infrastructure, water utilities are facing growing financial concerns (Saleth & Dinar, 1999; Seidenstat, 2005). According to AWWA (2001), the numerous water networks reaching the end of their life expectancy are stressing the budgets of many utilities and governments, and thus, such a financial pressure could facilitate innovations including proactive water-loss management.

External Factors: Environmental Constraints

Most prescriptive literature presumes that individuals do not accept change unless it is preceded by incentives, penalties, or processes that induce attitude changes (Kelman, 2005). All organizations are subject to two categories of environmental constraints, technical and institutional (Fennell & Alexander, 1993). Environmental change, according to population ecology and institutional frameworks, is a key determinant of organizational change. According to North (1994), human-devised institutions provide society with a structure of incentives that influences economic performance. Based on data analysis of the adoption of civil service reform, Tolbert and Zucker (1983) emphasized the important role of institutional pressure in adopting innovation.

Institutional theory emphasizes external pressure as the main source of influence on management decisions and it assumes that organizations respond passively to conform to their environments, which leads to criticisms that relates to the ignorance of the important roles of organizational interests and capacity (Oliver, 1991). Scott (1995) demonstrated that organizations were influenced by their institutional environments but that they were also capable of responding as active players by molding institutional patterns and mechanisms.

Barringer and Milkovich (1998) argued that the adoption of an innovation was to gain legitimacy, so "later"[45] adopters were more likely to behave according to prevailing practice while early adopters were more apt to establish a goal of improving organizational performance. Tolbert and Zucker (1983) confirmed that innovation adoption that stemmed from institutional pressure was likely to be rapid and direct from the state to each city. While early adoption could be strongly determined by organizational characteristics, they argued, late adoption was not, but instead, it was related to institutional definitions. In the absence of institutional pressure on water losses, organizational interests and characteristics might be important factors for innovations to deal with water losses proactively and the rate of adopting such innovations would gradually increase.

The social network in which the water utility operates is also important in the adoption of innovations, especially when the cost or risk of implementing an innovation is high. If an innovation requires a large fixed-capital investment with a long life span, uncertainty about costs may prevent a utility from adopting the innovation. Some programs of proactive water-loss management require a significant investment in the long-term, which results in the low adoption level of such programs. As a result, to reduce the cost or risk of implementing innovations, organizations will often depend on external mechanisms including associations, consultants, or other governments.

Researchers have identified the importance of a social network in the spread of innovation; for example, a group may play a strong role in pressuring its members to

[45] Barringer & Milkovich regarded "later" as when practice had become semi- or fully institutionalized.

adopt an innovation or disseminating information that encourages the adoption of an innovation (Valente, 1994; Tracey & Clark, 2003). As an illustration, the California Urban Water Conservation Council (CUWCC) has required its members to implement and report best management practices (BMP) of water conservation, so many water utilities in California are employing innovative practices. Tidd (2002) documented the reasons and the efforts to collaborate using transaction cost analysis and a strategic learning framework.

However, not all organizations in a network seem to collaborate. Barzelay (1992) found that local-oriented organizations were unlikely to be influenced by experiences in other states, so the role of geography in relation to the construction and functioning of alliances might contribute to strengthening the social network that encourages innovations. Danziger & Dutton (1977) found clear regional differences in the level of technological innovation adoption in local governments. They revealed a higher level of innovation adoption in the western and southern regions than in the northeast and north central regions. Since most water providers are part of local government, the level of water losses may differ from region to region.

The water industry in the United States consist of a variety of networks – international, national, and regional –that appear to be very active[46]. Even several public water utilities have made efforts to improve their performance and financial situation by

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[46] IWA, AWWA, and many other regional water associations provide a variety of journals, books, training courses, conferences, and workshops to share information and facilitate collaboration.

launching public-private partnerships[47]. Despite the lack of research on the roles and the influences of networks in the water industry, the more active and wide-ranging networks appear to be assisting and collaborating with utilities to solve problems that include water losses.

Summary: Integration of Internal and External Factors

Researchers have applied different theoretical frameworks to identify the key factors affecting decisions over innovations and categorized into two sectors: external and internal factors. The former is likely to be related to motivation for innovations that an organization does not actively control, while the latter is likely to be associated with the ability of an organization to implement innovations. Although Sundbo (2001) argued that internal driving forces are the core of the innovation process as no innovations would be existent if external factors did not motivate managers and employees to take action, many researchers have considered both internal and external factors important. Daft and Becker (1978) maintained that the external environment where incentives and innovative alternatives emerge and the internal structure and abilities of the organization to enable the adoption were both vital[48]. That is, an integrated approach to identifying the factors related to adopting innovations may produce more reliable information.

Danziger and Dutton (1977) identified several determinants of technological innovation in the local government, such as features of population served, support from

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[47] The City of Akron, OH and the city of Tyler, TX have reduced energy use in public facilities and upgraded water meters by contracting out some services to private firms.
[48] Daft and Becker didn't use the terms of 'external' and 'internal' directly, but the terms of the 'environment' and the 'organization' can be interpreted in that way.

external funding, the decentralization of decisions, characteristics of the region, the level of control of elected officials, and the level of professionalism. They suggested that other factors, including the technical or physical constraints, the severity of the problems, and attributes of the technology, and environmental and organizational characteristics, might also contribute to innovation.

Daft and Becker (1978) also listed a number of factors that stimulated innovation: the characteristics of the organization itself, including the ability of the organization to adopt innovations, which is determined by size, organizational growth, the amount of organizational slack resources, organizational complexity, centralization, and the attitude of managers and board members; innovation alternatives or the organizational mechanism for developing new ideas, including the administrative ratio, professionalism, exposure, and the availability of support staff; and environmental incentives such as more demand, competition, and other motivating factors. They found that the other incentives and organizational characteristics as well as the efficiency of the organizational mechanism for developing innovations affected decisions to adopt innovations.

Summarizing the sociological research on innovation, Downs (1976) listed several organizational characteristics associated with the adoption of innovation: "complexity, heterogeneity, formalization, impersonal relations, job satisfaction of employees, organizational structure, rate of environmental change, contact with information sources, slack resources, the presence of crisis, specialization, conflict-reducing mechanisms, and participative decision-making" (p16). Even though the sociological approach overlooked the role of the organizational environment, the interaction of determinants, and the necessary discourse between data and theory, Downs argued that such a list would be helpful in identifying significant factors determining innovation adoption. Downs also made a list of the attributes of innovations that determine adoptability: “financial cost, social cost, returns of investment, efficiency, risk, communicability, clarity of results, compatibility, pervasiveness, complexity, perceived relative advantage, demonstrability, terminality, reversibility, divisibility, degree of commitment, impact on interpersonal relationships, publicness, number of gatekeepers, susceptibility to succession modification, gateway capacity” (p19). He also included the characteristics of individuals who innovate: “education, social status, achievement motivation, undogmatic, intelligence, venturesomeness, imaginativeness, sociableness, cosmopoliteness, dominance” (p21).

Pierce and Delbecq (2001) presented a variety of factors that were frequently posited as being associated with innovations: structural variables, which include differentiation, professionalism, decentralization, formalization, and stratification; contextual variables, which consist of environmental uncertainty, size, age, and inter-organizational interdependences; and individual variables, which include attitudes such as job satisfaction, performance dissatisfaction, and intrinsic motivation and values of the decision makers favorable toward change. Their findings are not conclusive, but their study formulated exploratory, combinatory models by linking contexture, structure, and membership variables.

Borins (1998) presented several conditions leading to innovations in the public sector, such as internal problems, new opportunities, crises, political factors, and new leadership. He also identified some obstacles to innovation, such as bureaucratic attitudes, “turf” fights, other bureaucratic resistance, coordination difficulties, logistics problems, inadequate resources, regulatory constraints, political opposition, external doubts, affected private sector interests, public opposition, and private sector competitors. Other obstacles he identified were maintenance of enthusiasm, implementation of technology, opposition by unions, opposition to entrepreneurs, and the ability to reach target groups.

Although innovation research is somewhat inconsistent and anecdotal, a variety of factors listed above are helpful enough to develop the survey questionnaire to identify factors that affect management decisions over proactive water-loss management. Table 2 summarizes the factors associated with the adoption of innovation discussed in this section.

Table 2. Factors Associated with the Adoption of Innovation

Internal factors	External factors
1. Organization size & growth	1. Institutional pressure
2. Structure (stratification & complexity)	2. Social network
3. Organizational heterogeneity	3. Regional differences
4. Centralization	4. Population growth
5. Professionalism	5. External funding support
6. Leadership (internal advocates)	6. Technical constraints
7. Employee (participation & satisfaction)	7. Risk of innovation
8. Slack resources	8. Political support
9. Financial crisis	
10. Severity of the problems	

CHAPTER 3

METHODS

This chapter presents a conceptual model and the methods to identify the factors associated with water losses, including the factors that could influence management's decisions regarding the adoption of proactive water-loss management.

Conceptual Model: Hypotheses

As previously described, water losses are likely to be affected by three different categories of factors: operation and maintenance, internal and external factors. Due to its direct relationship with water losses, the operation and maintenance (O&M) comprise the initial framework in which water losses can be explained. From the technical or engineering standpoint, infrastructure conditions, the key determinant of water losses must be accounted for. From the perspective of organizational management, it is vital to analyze the relationship between water losses and other operational factors such as operational efficiency and costs and water quality.

Among the multiple O&M factors, some are likely associated with increased water losses, but for others, the direction of the correlation is ambiguous. Factors associated with increased losses are those related to system size, density, system age, and system pressure[49]; whereas factors such as system rehabilitation, operational efficiency, water quality, and O&M costs could have a negative association. Several factors such as

[49] Since the relationship between system pressure and water losses is recently focused on, there are no sufficient data available for a statistical analysis, even though some case studies are available.

pipe size and water-loss history can be both positively and negatively associated with water losses. For example, although the failure of large-diameter pipes can cause significant water losses, they will probably be repaired more rapidly. By contrast, the failure of small-diameter pipes might cause much less water losses, but they are also less likely to be detected and repaired. Even though it is hard to identify the impact of water-loss history without a consistent analysis over time, such a history is imperative as a determinant of water losses affects infrastructure conditions and measures that utilities use to combat water losses. To address the effect of O&M factors on water losses, this study will test the following hypotheses:

- H_1: A large size utility that has the extensive system lines, serves more population, and produces more water is likely to experience more water losses.
- H_2: The level of infrastructure rehabilitation is inversely related to water losses.
- H_3: Pipe size influences the extent of water losses.
- H_4: System age is positively correlated with water losses.
- H_5: A utility with high service density is likely to have more water losses
- H_6: Higher costs of operation and maintenance are associated with decreased water losses.
- H_7: Higher operational efficiency of a utility is likely to result in less water losses.
- H_8: Efforts to improve water quality are likely to result in less water losses.
- H_9: The current level of water losses is related to water-loss history.

To develop strategies to improve performance, an organization must first conduct a comprehensive evaluation of its own strengths and weaknesses. To identify the internal factors associated with water losses, this study will analyze several organizational characteristics and management techniques. One such characteristic is the maintenance of good customer relations and the implementation of strategic planning and management, both of which are likely to reduce water losses. However, data on organizational culture and structure – except the number of employees- are difficult to obtain, so data from case studies are needed. Despite a lack of prior evidence regarding the relationship between customer mix and water losses, the size of pipes and the amount of water delivered usually differ by customer type, so customer mix might influence water losses because of different service systems.

In addition, strategic management practices such as proactive water-loss control[50], water conservation programs, and high metering rate are likely to decrease water losses. However, such strategies often incur higher costs. Total size of funds and the way to manage capital financing and debt are associated with water losses by making an impact on slack resources available to control losses.[51] For example, while a water utility with substantial revenues and assets may have resources to invest to control water losses, a utility with a lot of debt or liabilities to pay may have difficulties in finding extra resources to manage water losses. If major sources of funding for capital investment are revenues or grants, water losses are more likely to decrease than if they are in the form of loans. Also, high water rates and the cost coverage ratio may reduce water losses. In

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[50] There are no datasets available to test the impacts of proactive practices on water losses in a statistical framework. Maybe, the 2002 AWWA survey dataset can be useful, but this study does not use this dataset for a statistical analysis (refer to the next section named as case studies).
[51] Unless water-loss control is implemented in the routine processes of O&M, proactive practices can be employed when slack resources are available. However, it is difficult to measure the amount of slack resources, so the relationship between slack resources and water losses cannot be tested here.

accordance with the allocation of capital expenditures, water losses can increase or decline. To address the internal factors, this study will test the following hypotheses:

- H_{10}: The diversity of the customer base is associated with the different levels of water losses.
- H_{11}: Efforts to provide good customer assistance and service are more likely to lead to reduce water losses.
- H_{12}: The number of employees is associated with the level of water losses.
- H_{13}: A higher rate of meter readings decreases water losses.
- H_{14}: Demand-side water conservation and supply-side conservation are related.
- H_{15}: A higher cost coverage ratio reduces water losses.
- H_{16}: Higher water rates are negatively correlated with water losses.
- H_{17}: More capital expenditures on distributional system decrease water losses.
- H_{18}: A high level of debt or liabilities is associated with a high level of water losses.
- H_{19}: More assets or revenues reduce water losses.
- H_{20}: Use of revenues or grants, rather than loans, to fund capital investment reduces water losses.

The external factors are binding constraints for water utilities, as they have no power to control them. The impact of these factors must be controlled in the empirical analysis, in order to get consistent estimates of the impacts of those factors within the utilities' control. Although ownership might be considered as an internal factor, ownership is normally defined in the public domain in the United States, so the utility cannot change its ownership status. Thus, it is considered an external factor in this study.[52] Although the private utility ownership has not been consistently evaluated with respect to efficiency, we conjecture that privately-owned utilities are apt to be more sensitive to revenue and water losses. In addition, sufficient water resource and decreased water demand can make water-loss control infeasible from an economic perspective, but institutional pressure on water losses will encourage water-loss control. However, the impact of type of water source is unclear. In sum, to assess the external factors that lead to water loss, the following hypotheses will be tested:

- H_{21}: Privately-owned utilities are more likely to make an effort to reduce losses.
- H_{23}: When a utility faces supply constraints, a high level of water losses will pose a major problem, which prompts water-loss control.
- H_{24}: Different water sources will result in various levels of water losses.
- H_{25}: Higher water demands reduce water losses.
- H_{26}: Utilities that are required to control or report information on water losses are likely to make more efforts to reduce losses.

In summary, the three categories of factors are conjectured to affect water losses directly or indirectly. The direction of the impacts can be positive or negative. Some factors might exert effects that are independent of other factors, but other factors work in

[52] The scope of the commission regulation of water systems includes ownership in the most states (Beecher & Laubach, 1989). That is, ownership is controlled by outsiders.

a network. Figure 3 illustrates the relationship between water losses and factors in three different categories.

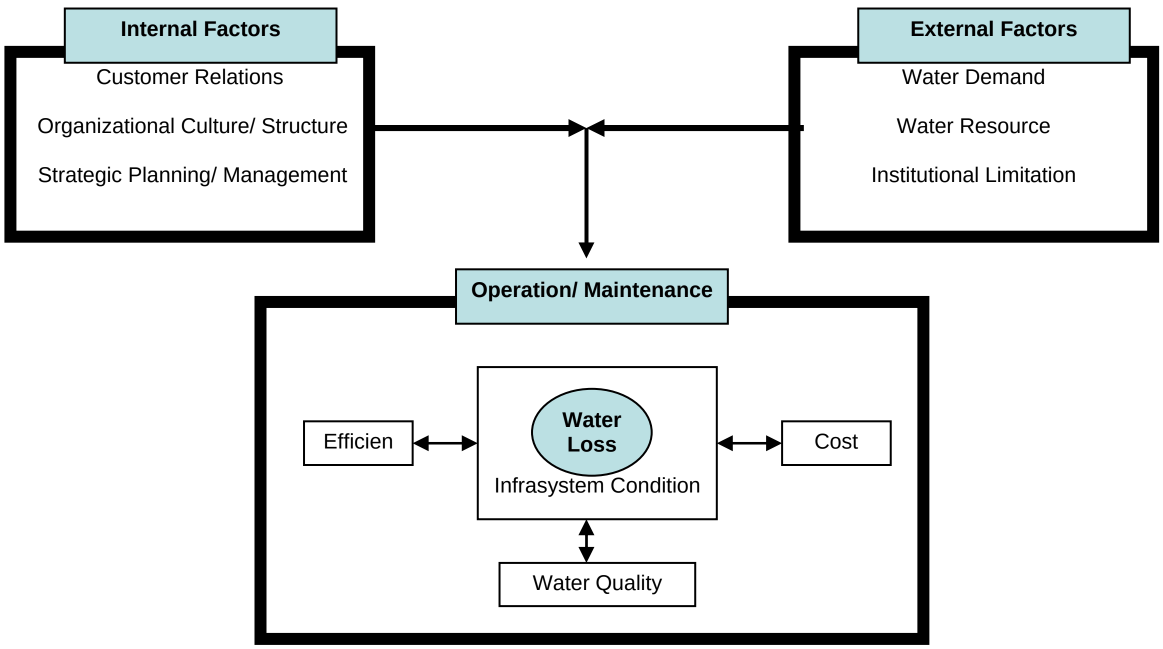

Figure 3. Conceptual Model for Water Loss

This study will also identify influential factors that affect management's decisions to adopt proactive water-loss management by extrapolating from innovation research conducted in other sectors. We categorize the factors identified in this research into external and internal factors, both of which have been utilized to develop survey questionnaires. Because case studies are conducted and analyzed in a descriptive framework, any hypotheses formulated for the case studies are not subject to empirical tests. We conjecture, however, that internal factors play a bigger role than external factors because institutional incentives and penalties for water losses have not been broadly established in the United States.

Data Analyses

This empirical work carried out in this study uses statistical analyses for three different datasets. Although the use of different datasets allows for a more comparative and comprehensive analysis, they produce inconsistent results because the datasets were created for different purposes, by different organizations, and at different times. Furthermore, neither their reliability nor their quality has been scrutinized by other research. Given the lack of a standard definition of water losses in the U.S. water industry, the comparability of the datasets regarding water losses is questionable.

To ensure more reliable and comprehensive research, this study will first examine the similarities and differences found in the three datasets. Each dataset is analyzed with empirical models that are similar, but have substantive differences do the availability of key variables. All models in this study share the conceptually same dependent variable. Two of the datasets have the same format for the dependent variable and some of the same independent variables, so the results of these analyses are more easily compared.

Water losses can be computed based on various standardizations and normalizations. Water losses expressed in percentage terms and water losses computed on a per mile of pipe basis are more useful to the utility than, perhaps, to the water industry or society because these measures help to evaluate organizational efficiency or engineering issues. The total amount of water losses is a more valuable measure from the perspective of water conservation.

Information on external factors of water utilities such as socio-economic and environmental information has been gathered from government or public databases, including the Fedstats and the Bureau of Census. To find a proxy for water resource availability, this study utilizes the average yearly precipitation data by city[53] over a 30-year period (1961-1990); these data come from the Fedstats website. The rate of population increase proxies for the changes in water demand as does median household income. These statistics population change over a 10-year period (1990-2000) and 1999 median household income per city or county from the census database.

Data on information asymmetry and institutional pressure are obtained through Beecher's survey (2002). Each state has established different requirements for water losses, which impacts water-loss management as well as the level of water losses. The EPA dataset does not include the state identifier, so the EPA dataset cannot be combined with other external datasets.

The American Water Works Association (AWWA) Dataset

The first dataset comes from the AWWA Water Stats 1996 Distribution Survey CD-ROM which is based on the first nationwide survey on water distribution systems.

Data Description

[53] The socio-economic and environmental information of a service area is not available, but the information on the city where a utility exists may useful to guesstimate the situations of the service area and resource availability.

Table 3. Variables in the AWWA Dataset

Section	Sub-Section	Variables
General information	Name Location Ownership Size Estimated Water Demand Residential Info Service Types	Utility Name City& State Category & Type of Ownership Population Served & Service Area Increase % by 2000 Gal/year, Cost/year Drinking, Wastewater, and so on
Production/ Delivery	Annual Production Annual Sale Volume	GW, SW, Purchased, & Total Total & Per Customer Type
Financial information	Financial Ending Capital Info Budget O&M Expenses	Date Assets, Liabilities, Debt, & Reserve Fund Last, Current, & Projected Total Budget Total O&M Expenses
Distribution Pipe/ Main Breaks	No. of Hydrants No. of Main Breaks Retention Time Miles of Main Pipe Service Lines	Number of Hydrants In 1991, 1992, 1993, 1994 & 1995 Average & Maximum Retention Time In-place, Replaced, & Expansions % of Lead Replaced & Miles of Fire lines
Distribution Pipe Material	In-Place Replaced Expansions	Mile Percentage Per Material Types (Cast-Iron, Asbestos-Cement, Concrete-Pressure and so on)
Distribution Fire Service Lines	Miles of Fire Lines Percentage of Fire Lines	Dedicated Fire Service Lines Per Material Types
Distribution Customer Service Lines	Percentage of Lines Lead Pipe Replaced	Per Material Types % Lead Replaced Annually
Distribution Storage	Current Storage Future Storage	No. & Capacity Per Different Types of Storage Facilities
Treatment Plant Information	Surface Water Treatment Ground Water Treatment	Source, Capacity, Pretreatment, Pilot Plant. No. of Wells, Capacity, Expansion, Surface water influence, Protection, & Entry Points

The survey questionnaire included over 200 questions, and a total of 898 water utilities among the 3,200 AWWA member utilities responded. The AWWA dataset provides a variety of information about water losses, including leak management, supply auditing, customer metering, infrastructure, fire hydrants and flushing, customer service lines, water conveyance, and basic utility characteristics. As seen in Table 3, the AWWA dataset covers almost every O&M and internal factors except operational efficiency and organizational culture and structure. It includes some external factors, and the information about the location allows for the integration of other data such as weather, socio-economic, institutional requirement, and violation data.

Data Processing

The AWWA 1996 survey requested considerable information, but not every question was answered. Among the 898 respondents, only 534 utilities provided information on productions and deliveries, necessary to calculate water losses, the key variable. The total amount of water losses is calculated by subtracting the sum of revenue water and authorized public uses from total water produced based on the conceptual framework (see Figure 1). If a water utility has negative water losses, the observation is crossed out because the negative signal indicates a serious error of auditing and thus the data quality is unreliable. Nevertheless, almost half of the remaining observations have other missing data. Only 250 utilities provided more or less complete responses to the survey consistently; these are used for the data analysis.

Model

Since this dataset provides substantial O&M data, mainly on infrastructure conditions, the percentage of water losses and water losses per mile are more appropriate for a dependent variable. Each of the two dependent variables is analyzed in different empirical models based on the simple linear regression:

$$\text{Water Loss (\% or MGY}^{54}\text{/mile)} = \beta_i + \sum b_i X_i$$

b_i: coefficient of each independent variable

X_i: independent variables

Table 4. Potential Independent Variables in the AWWA Dataset

O&M Factors	Internal Factors	External Factors
Population (by customer type) Density Production O&M costs # of Main breaks by year Miles of pipe (total, replaced, extended) % of Lead Replaced pipe	Customer type (water, bill) Assets Liabilities Debt Reserve Fund Budget by year	Ownership Demand increase % Source type (GW, SW, PW) Precipitation (state., local) Location (west, EPA region)

The Raftelis Financial Consulting, PA (RFC) Dataset

Raftelis Financial Consulting, PA (RFC) has conducted biennial rate surveys since 1996, and this study utilizes the 2002 survey, which provides the most recent data.

<u>Data Description & Processing.</u>

The RFC data provide detailed information on utility operating, financial, billing, and pricing characteristics of 153 water utilities in 48 states, and the data are current as of the 2000 or 2001. Table 5 shows variables in RFC dataset. Most respondents provided information consistently, but 130 water utilities that shared data on water losses are selected for the next step. In accordance with geographic location, the data of external factors are combined.

[54] Million Gallons per Year

Table 5. Variables in the RFC Dataset

Section	Variables
System Characteristics	Population, Ownership, Sold water, Daily capacity, Maximum production, Annual water loss, Water sources type, Capital needs, # of full-time employees
Water Charges	Rate structure by customer type, Monthly water charges per meter size or customer type and by monthly water consumption
Other Water Charges	Connection fee and other surcharges, Monthly service minimum charge per customer type.
Water Financial & Billing	# of accounts, Billing type and cycle, Revenue, Operating cost, Total assets, Long-term debt, Total equity, Type of water conservation, Payment assistance
Affordability	Median household income, affordability index by monthly water consumption

Model

The focus of the RFC survey was water finance and pricing, key internal factors, and intended to help develop strategic planning and management that promoted organizational efficiency. However, data about infrastructure conditions were not available. Based on a variety of internal factors, the percentage of water losses seems to be a good fit as a dependent variable. The empirical model of the RFC is also based on the simple linear regression to maintain consistency in the study, but the independent variables are quite different from those in the AWWA dataset:

$$\text{Water Loss (\%)} = \beta_{ii} + \sum c_i X_{ii}$$

c_i: coefficient of each independent variable

X_{ii}: independent variables

Table 6. Potential Independent Variables in the RFC Dataset

O&M Factors	Internal Factors	External Factors
Population Sold water Daily capacity Maximum production Operating cost Operational efficiency	Capital needs # of full-time employees Rate structure Water rates Additional fee and surcharges Minimum charge Revenue Assets Debt Equity Water conservation Customer assistance Customer type Cost coverage ratio	Ownership Median household income Source type (GW, SW, PW) Location (west, EPA region)

The United States Environmental Protection Agency (EPA) Dataset

The last source of data is the EPA. Since 1976, the U.S. EPA has conducted the Community Water System (CWS)[55] Surveys to obtain data for regulatory, policy, implementation, and compliance analyses, and published reports that provide an overview of the performance of water systems by ownership type and size. This study uses the dataset derived from the recent CWS Survey conducted in 2000.

Data Description

The EPA dataset includes a variety of operating characteristics and general information of over 1,200 U.S. CWS. It provides comprehensive data related to O&M and internal factors, but few data on external factors.

[55] EPA defines CWS as a water system that provides water to the same population year-round and the US has total 53,363 CWS.

Table 7. Variables in the EPA Dataset

Section	Variables
Operating information	Ownership, Water deliveries per customer type, Total water production, Water source, Treatment info, Storage, info Pipe length by size, Replaced pipe & costs by size, Pipe age, Customer type, Cross-connection control,
Financial information	Water sales by customer type, Non-water revenue, Avg. annual bill, Billing structure, Metered billing, Low-income assistance, O&M cost, No. & Costs of Employee, Debt, Capital expenditure, Funding sources

Data Processing

The EPA dataset does not provide data to calculate total amount of water losses, but the data on unaccounted-for-water (UFW) are available. Given the lack of a standard definition for water losses, UFW is difficult to distinguish from total water losses. The CWS survey asked the respondents to reveal the amount of UFW but it explained UFW as non-revenue water (NRW) by including uncompensated usage as well as system losses. That is, the data on water losses in the EPA dataset may represent NRW, UFW, or total water losses. However, since these three concepts are closely related and have been used to represent water losses, the concept of UFW in the EPA dataset is substituted for water losses.

Since this dataset is larger than the others, more data processing is required. Inconsistent data are deleted, based on several criteria. If a utility had zero pipe miles, or longer replaced pipe lines than the total, or more deliveries than total produced water, the data were eliminated from the analysis. Also, this study selects data only when information on water losses is available, which leaves 917 utilities in the dataset. Some missing values are able to be calculated by other information because some variables include both total value and sub-category values. If all delivery information but not water-loss information is provided, water losses are the same as the difference between total production and the sum of deliveries. Water deliveries to residential or nonresidential customers are also calculated when total deliveries and other deliveries are available. Any missing values for total deliveries can be filled in by adding all water delivery values. After double-checking total deliveries against the sum of all deliveries, misplaced total production and total deliveries are exchanged. In addition, replaced pipe miles and replace costs can be used to locate mutual missing values[56].

Model

Because the data set provides more information, the EPA data allows us to consider various measures for the dependent variable. Per mile water losses and total gross water losses are useful for organizational or engineering efficiency as well as for an overall perspective of water conservation. Furthermore, log (water losses) is analyzed in another model to reduce the scale problem. That is, three different units of water losses are analyzed in three different empirical models. Similar to those in other datasets, these models are specified as linear regression:

Water Loss (MGY or MGY/mile or log(MGY)) = $\beta_{iii} + \sum d_i X_{iii}$

d_i: coefficient of each independent variable

X_{iii}: independent variables

[56] If pipe is replaced, the replacement costs cannot be \$0. If the costs of replacement are \$0, the replaced pipe seems to be 0 miles.

Table 8. Potential Independent Variables in the EPA Dataset

O&M Factors	Internal Factors	External Factors
Population	Revenue	Ownership
Pipe size	Residential bill	Source type (GW, SW, PW)
Pipe length	Billing structure	
Pipe age	Customer type	
Operating cost	Customer assistance	
Production	Metered billing	
Deliveries per customer type	# of employees	
Treatment	Debt	
Cross connection control	Capital expenditure per type	
Operational efficiency	Funding sources	
	Cost coverage ratio	

Case Studies

To overcome the limitations of data availability, this study analyzes the factors that influence the adoption of proactive water-loss management based on case studies. While demand-side water conservation requires the cooperation of customers, supply-side water conservation relies on the capabilities and perception of water providers, so it is important to understand the manager's perception and the capabilities and characteristics of a water utility. Therefore, the target respondents of the survey questionnaire are managers of water utilities who have adopted and implemented proactive water-loss management or who have an authority to make a decision over the adoption of the management.

The survey questionnaire was designed to identify factors that the managers perceive as motivators of decisions related to water-loss management and understand their perceptions on their organizational culture, structure, and issues. In addition, the survey explores potential factors associated with water losses as well as the management. The questionnaire consists of three parts[57]. The first part collects information on water losses and the management of water losses, including the causes of water losses and the ways of responding to them. This part of the questionnaire also explores managers' perceptions on adoptions and success of water-loss management and some issues related to water losses. The second part collects information on culture and structure and network of the utility organization. The last part of the questionnaire obtains general information such as production, costs, revenues, and rates, and identifies the important issues the utilities are facing.

To increase the response rate, the study minimizes the length of the survey, which will fail to provide in-depth information. To solve this problem, this survey is combined with another dataset: the 2002 AWWA dataset[58]. The nationwide survey on distribution systems conducted by AWWA in 2002 provides extensive distribution system data, including water losses of 330 U.S. water utilities. However, many utilities did not provide consistent answers and some coding errors were detected, which did not allow statistical analysis[59]. This study selects approximately 100 utilities that provided reliable answers in the 2002 AWWA survey as the target participants for the new survey, so this study is able to combine the extensive distribution system data with the new survey results.

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[57] Refer to Appendix A to see the whole survey questionnaire.
[58] The data comes from the AWWA WATER;\STATS 2002 Distribution Survey.
[59] Even though this dataset is not analyzed within the statistical framework, a lot of information for the case studies comes from this dataset, so to increase data reliability, approximately 100 utilities that provided inconsistent answers were dropped from the dataset.

Based on the information from the 2002 AWWA dataset, the target utilities were divided into two groups: a focus group and a control group. The focus group includes the utilities that have already implemented proactive water-loss management. That is, if a utility put at least one active loss-control program into practice or if it sets a loss-reduction target, the utility was placed in the target group. If not, it was considered as the control group. The survey was web-based and the slightly different questionnaires were delivered to each group.

Although the anecdotal case studies have limited explanatory power, this practical approach collects not only perception-based data from the survey but also in-depth information from the combination with the 2002 AWWA dataset. Thus, this study is able to yield a more comprehensive framework to explain management's decisions to adopt proactive water-loss management. The results will be analyzed within a descriptive framework.

CHAPTER 4

FINDINGS OF THE DATA ANALYSES

Three datasets with different models produce different results even though they include some of the same conceptual variables. First, the results of each dataset are discussed separately, but in the end, all the results are discussed together.

Results of the AWWA Dataset

The following table describes the variables used in the AWWA dataset.

Table 9. Description of the Variables in the AWWA Models

Dependent Variable	
Loss/Mile	Total annual water losses / Total pipe mile (MGY/Mile)
Loss_%	Total annual water losses / Total annual water production (%)
O&M Factors	
log(O&M)	log(total operation & maintenance expenses), in dollar
log(production)	log(total annual water production) in MGY
Medium	1 if the average daily population served is between 3301 and 10000, 0 otherwise
Pop/sq_Mile	Population served per retail service area (square miles)
Replaced Mile	Total miles of main pipe replaced last year (in 1995)
Extended Mile	Total miles of main pipe installed last year due to system expansions (in 1995)
Breaks_1994	Number of main breaks in 1994
Breaks_1995	Number of main breaks in 1995
Internal Factors	
Residential Bill	Total cost per year for an average single-family residence
Bill_Private	Interaction term created by multiplying residential bill times private owner
log(liability)	log(utility's total liability), in dollar
log(debt)	log(utility's total debt), in dollar
External Factors	
Private Owner	1 if a utility has private ownership, 0 otherwise
EPA_6	1 if a utility in the EPA region 6, 0 otherwise
Surface Water	1 if surface water is a primary source, 0 otherwise
Demand_Inc_%	Estimated increase percentage of water demand by 2000
log(income_99)	1999 median household income in the service area
Precipitation	Average yearly precipitation (inch/yr)

Table 10. Results of the AWWA Model (Loss/Mile)

Linear regression					Number of obs = 205 F(13, 190) = 3.19 Prob > F = 0.0000 R-squared = 0.3024 Root MSE = 2.3783	
Loss/Mile	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval	Beta
log(O&M)	-2.423079	.9430856	-2.57	0.011	-4.283735 -.5633344	-.4889627
log(production)	3.569353	1.067543	3.34	0.001	1.463665 5.675042	.7480004
Medium	1.7358	.502724	3.45	0.001	.7441957 2.727404	.0620758
Pop/sq_Mile	.1808226	.1087363	1.66	0.098	-.0336557 .3953009	.3452851
Replaced Mile	-.0045708	.0023669	-1.93	0.055	-.0092394 .0000977	-.0357973
Extended Mile	-.0123079	.0066412	-1.85	0.065	-.0254073 .0007915	-.0948117
Breaks_1994	-.0039053	.00123520	-3.16	0.002	-.0063417 -.0014688	-.565151
Breaks_1995	.0047912	.0018311	2.629	0.010	.0011793 .0084031	.579359
Residential Bill	.002952	.0013472	2.19	0.030	.0002948 .0056092	.1219226
log(liability)	.4599494	.2538757	1.81	0.072	-.0408109 .9607096	.1490562
log(debt)	-.8666387	.5146662	-1.68	0.094	-1.881798 .1485208	-.2569742
Bill_Private	-.002453	.0010272	-2.39	0.018	-.0044791 -.0004269	-.0793728
EPA_6	-.8670112	.4056405	-2.14	0.034	-1.667122 -.0669008	-.0740549
_cons	7.229336	3.7761545	1.92	0.056	-.1901695 14.64884	

Table 10 shows the regression results using the AWWA dataset. The AWWA dataset provided numerous variables that pertain to O&M, so this first model included more O&M factors than internal and external factors. As expected, the study finds support for hypothesis number six; there is evidence that higher expenditures on O&M reduced water losses. This relationship makes sense because these costs include expenditures on replacement and repairs of distributional systems as well as routine operational costs. The results provide strong evidence that system size affects water losses. A one percent increase in production raised water losses by 3.57 MGY per mile. Not surprisingly, the impact of production on water losses was relatively large and statistically significant in this model. Mid-size utilities do not seem particularly efficient in terms of water-loss management; the results indicate that these utilities experienced more water losses than larger utilities that served more than 10,000 people daily.[60] In addition, they are likely to have smaller O&M costs[61], so water losses generated in these utilities are not controlled effectively.

At a significance level of 0.1, a utility with high service density was likely to have more water losses (H_5). If a utility has the bigger value of "Pop/sq_Mile," the utility serves more people than other utilities that have the same size of service area. More people served may require more connections. As discussed in Chapter 2, the number of service connections is a very important factor in assessing water losses in urban distribution systems.[62] That is, marginally, this study confirmed that high service density requiring more connections is associated with increased water losses.

As anticipated in hypothesis four (H_4), newly replaced or installed pipes were less likely to have leaks and breaks, which resulted in a lower level of water losses per pipe mile; the results indicate that this effect is significant at a 10% significance level. Water-loss history also has a highly significant influence on the current level of water losses, as

[60] No smaller-size utilities are included in this sample, so the medium-size utilities are the smallest in terms of population served.
[61] At a significance level of .05, log(O&M) and medium are negatively correlated (-.2185).
[62] Alegre et al. (2006)

suggested in H_9. Main breaks in both 1994 and 1995 had an impact on water losses per mile, but the events apparently work in opposite directions. This is puzzling. One might conjecture that whereas most reported or detected breaks are repaired, the repairs are not immediate. The length of time that a leak exists varies, but it sometimes takes several months for the repair to made.[63] This is, due to the long lag time from report to repair, it is somewhat more likely that the earlier breaks (in 1994) had been repaired whereas relatively recent breaks (in 1995) could still be causing water losses.

Contrary to prior expectations as stated in H_{16}, higher water bills were not associated with reduced water losses on the supply-side. It is possible that there is an incentive for a utility not to take action to curb the losses when a water bill is going up. Clearly, utilities that lose more water in the system and deliver less water to customers have decreased water revenue. However, to recover revenue losses, they do not necessarily take action to improve system efficiency, which reduces water losses and increase water revenue. Instead, they may attempt to increase water rates to recover revenue losses. Even though raising water rates requires political processes to gain approval, the current process of rate increase approval do not seem to consider system inefficiency which could be the source of revenue losses. Most board meetings of public utility for rate approvals focus on the financial need for the rate increase, how much of an increase is appropriate, and what impacts on customers are expected, but not on how efficiently utilities operate the systems. So, a utility can win approval much more easily if it is facing apparent financial difficulties. Since such financial problems are the primary

[63] Refer to the Chapter 5

consideration for rate increase approval, and the level of information asymmetry between water utilities and decision-makers is relatively high[64], it can be easier for a utility that has a high level of water losses and a low level of revenue water to gain approval for rate increases than for a utility that manages water losses effectively. That is, the level of water losses may be high when water utilities can charge their customers more because the imperfect institutional framework allows utilities to attempt to recover revenue losses through rate increases rather than improvements in system efficiency.

This model includes an interaction term by multiplying the dummy variable indicating private ownership by the variable, residential bill. This allows us to test the possibility that the size of the residential bill has a different impact on water losses for private utilities than for public utilities. The coefficient on interaction term shows that water losses per mile decrease by .0034611 with each dollar of residential bills for a private utility. It is much harder for private utilities than public utilities to win rate increase approval, so public water utilities are likely to have a higher level of water losses when a bill is going up. The results support that a higher water bill is related to a lower level of water losses in private utilities while there is a positive relationship between water bills and water losses in public utilities.

These results suggest that a utility with a higher burden of liabilities experiences more water losses whereas utilities with higher levels of debt experience fewer water losses. As expected in hypothesis number eighteen (H_{18}), financial obligations such as

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[64] According to Dziegielewski, B., Kiefer, J., & Bik, T. (2004), recovery of costs associated with operations, capital, and overhead costs is the main consideration in the rate design, and many water systems in Illinois do not have huge political influence in the rate design and approval process.

liabilities would limit the ability of a utility to deal with water losses. Contrary to the anticipation that higher debt loads would have the same impact (H_{18}), debt are negatively related to water losses. Perhaps for the utilities in this sample, debt is used to finance improvements to system efficiencies, which would result in lowering water losses. The variable of log(debt) was significantly correlated with replaced pipe miles and extended pipe miles.[65] Even though funds from debt were also likely to be positively correlated with system rehabilitation and extension, the positive impact of debt on water losses can not be explained fully without information on the decomposition of the debt.

The model using the AWWA dataset utilized EPA regions instead of states as geographic identifiers. The EPA identifies 10 different regions. Although utilities in the same region or even in the same state may not function under the same level of institutional pressure or within the same framework, the findings still can have a policy implication. This study found that utilities in the EPA region 6, which includes five states of Arkansas, Louisiana, Oklahoma, Texas, and New Mexico, had the lower level of water losses than other regions. The region 6 includes ten utilities from Texas and one utility each from the four other states. Thus findings for Region 6 are heavily influenced by Texas. Texas is the state with the most stringent regulations, requiring water utilities to perform water audits that assess their water losses.[66] According to a survey by Beecher (2002), Texas was one of several states that have various requirements and guidelines

[65] The correlation between log(debt) and replaced miles and the correlation between log(debt) and extended miles were statistically significant at a significance level of .05, and the values of the correlations were 0.1687 and 0.3215, respectively.
[66] Texas House Bill 3338

related to water losses.[67] That is, Texas has a strong institutional pressure to motivate utilities to take action against water losses and to share information about water losses with the public and regulators. The results suggest that this institutional pressure does result in less water lost.

Table 11 shows the results using the AWWA model, based on another model. This second model used a percentage as the dependent variable instead of water losses per mile and included more external factors for policy purposes. Most water-loss reduction targets set by the U.S. government or utilities are addressed by percentage, so water losses defined as a percentage may be more useful for identifying policy implications.

O&M factors such as operational costs, water-loss history, and system rehabilitation all had very similar impacts on the percent water losses as on the water losses per mile, with changes, of course, in the coefficients themselves. At a significance level of 0.05, breaks in 1994 and replaced miles were likely to reduce the percentage of water losses while breaks in 1995 were likely to increase it. In addition, a 1% increase in O&M costs might reduce water losses by 3.36% at a 0.1 significance level.

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[67] Based on survey, web and document investigation, and case studies, Beecher found that Texas implemented several regulations and guidelines to promote actions against water losses such as water-loss policies, definition of water loss, accounting and reporting, standards and benchmarks, goals and targets, planning requirements, technical assistance, performance incentives, and auditing and enforcement.

Table 11. Results of the AWWA Model (Loss %)

Linear regression					Number of obs = 230 F(10, 219) = 5.17 Prob > F = 0.0000 R-squared = 0.1195 Root MSE = 11.051	
Loss_%	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval	Beta
log(O&M)	-3.364705	1.721972	-1.95	0.052	-6.758463 .0290535	-.1677592
Breaks_1994	-.0108193	.0045509	-2.38	0.018	-.0197884 -.0018502	-.3664939
Breaks_1995	.0151028	.0067101	2.25	0.025	.0018781 .0283276	.4331306
Replaced Mile	-.0223062	.010885	-2.05	0.042	-.043759 -.0008535	-.039669
Private Owner	-2.735603	1.71113	-1.60	0.111	-6.107993 .6367876	-.0685662
Precipitation	.0943208	.0563572	1.67	0.096	-.0167512 .2053928	.1130825
Demand_Inc_%	-.2049293	.0760406	-2.69	0.008	-.3547942 -.0550643	-.1644813
log(income_99)	-10.93436	4.632979	-2.36	0.019	-20.06529 -1.803427	-.1476095
EPA_6	-4.417099	2.297155	-1.92	0.056	-8.944458 .1102602	-.0887591
Surface Water	2.98788	1.57023	1.90	0.058	-.1068159 6.082576	.1299533
_cons	85.34869	25.86388	3.30	0.001	34.37472 136.3227	

This model included all possible external factors such as ownership types, supply constraints, water source types, and regional identifiers to indicate institutional pressure and a framework for information asymmetry. Almost all of the results were as predicted. The impact of EPA_6 on water losses was similar to the results from the first model. Even though the coefficient was not statistically significant, a privately-owned utility was more likely to reduce water losses than a publicly-own utility. This yields some evidence to support the hypothesis twenty one that privately owned utilities are more concerned with loss-minimization than publicly owned utilities. However, the confidence interval of the variable included the value of 0, which indicated that ownership would not have an impact on water losses in the population.

At a significance level of 0.1, these results indicated that water utilities in areas with more water resources were less likely to attempt to reduce water losses. Precipitation, although, not an exact measurement of resource availability, can be a good proxy for resource availability, so this model confirmed a relatively weak relationship between resource availability and water losses. The variable of the median household income in 1999 was used to represent water demand. As this variable increased, the percent water losses was less, suggesting that increasing demands motivated utilities to focus on water conservation and efficient uses.

As predicted in H_{24}, different types of water source resulted in various levels of water losses. A utility that used surface water as a primary source of water was significantly more likely to experience water losses. Historically, water utilities have used surface water as a primary source, but more recently, utilities are using groundwater instead. As more utilities have shifted from surface water to groundwater than vice versa, utilities that use more groundwater have more possibilities that they have shifted their water sources. The shift of water source implies that the utility might have difficulties using the previous water sources and was more likely to consider strategies to improve system efficiency, which might result in reduced water losses. Therefore, a utility that uses a traditional primary source – surface water – may be less motivated to reduce water losses because it is less likely to face major supply constraints.

Results of the RFC Dataset

The percentage of annual water losses provided by the RFC dataset is conceptually the same as the one analyzed in the second model with the AWWA dataset. The RFC dataset provided a number of internal factors, particularly those related to finances and pricing, but only a few external and O&M factors. The following table describes the variables in the RFC model.

Table 12. Description of the Variables in the RFC Model

Dependent Variable	
Loss_%	Annual water losses (%)
O&M Factors	
Pop_served	Total population served
Maxprod_sq	Squared Maximum Daily Production
Efficiency	Revenue water/ full-time employees (MGD/employee)
Internal Factors	
Employee	Number of full-time employees
Cost Coverage	Annual revenue/Annual operating cost
Debt	Total long-term debt ($000)
Assets	Total assets ($000)
Rate_Industry	Monthly water charge for industrial users with 4” meter
Mini_Charge_In	Minimum monthly charge for industrial users with 4”meter
DB_Rate_Nonre	1 if a utility employs decreasing block rate structure for non-residential users, 0 otherwise
External Factors	
Purchased_%	The percentage of purchased water as a water source
West	1 if a utility exits in the western state, 0 otherwise

The RFC model included three O&M variables. The first one was system efficiency, a ratio of gallons of daily water sold and the number of total full-time employees. This study predicted in H_7 that a utility with high operational efficiency was likely to maintain the low level of water losses.

Table 13. Results of the RFC Model (Loss_%)

Linear regression					Number of obs = 91 F(12, 78) = 6.29 Prob > F = 0.0000 R-squared = 0.4037 Root MSE = 5.5735	
Loss_%	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval	Beta
Pop_served	.008798	.0029381	2.99	0.004	.0029486 .0146473	1.092178
Maxprod_sq	-.0000144	6.19e-06	-2.33	0.022	-.0000267 -2.09e-06	-.5194041
Efficiency	-4.893292	3.039919	-1.61	0.112	-10.94531 1.158722	-.1228666
Employee	-.0057403	.0019614	-2.93	0.004	-.0096451 -.0018354	-.4116025
Cost Coverage	-2.51665	1.393638	-1.81	0.075	-5.291169 .25787	-.1750484
Debt	.0000133	4.67e-06	2.84	0.006	3.95e-06 .0000226	.5078255
Assets	-7.73e-06	2.76e-06	-2.80	0.006	-.0000132 -2.24e-06	-.6907103
Rate_Industry	.000229	.0001086	2.11	0.038	.0000128 .0004451	.2192817
Mini_Charge_In	-.0084295	.0053653	-1.57	0.120	-.0191111 .002252	-.1778487
DB_Rate_Nonre	4.103894	1.470509	2.79	0.007	1.176335 7.031453	.3016753
Purchased_%	-.0348691	.0207009	-1.68	0.096	-.0760815 .0063433	-.1001753
West	-2.385975	1.168761	-2.04	0.045	-4.712799 -.0591518	-.1727383
_cons	13.18767	2.742866	4.81	0.000	7.727047 18.6483	

The results showed an inverse relationship between operational efficiency and system inefficiency, but it was not so statistically significant. The other two O&M variables were related to size. As expected in H_1 and consistent with the other results, a utility that served more people was likely to yield more water losses. The size variable based on population served had a relatively large and statistically significant impact.

Since no data on total production were provided, this model, which included maximum daily production as a proxy for total production seemed to have a curvilinear relationship with the dependent variable, so it was squared. Contrary to the expectation of hypothesis number one, the higher maximum daily production of a utility was, the less likely it was to yield water losses. One explanation for this unexpected result is either that the model included two similar size variables that were highly correlated and appeared to have a linear relationship (the value of correlation = .8751), or that the maximum daily production was not a good estimation for the annual total production.

Most internal variables in this model except employee were related to financial conditions of a utility. The number of employees can be another size-related variable, but it also represents organizational resource or capacity. This study found strong evidence that the more employees a utility had, the less water losses it was likely to be experience. That is, employees are useful resources for water-loss management.

At a significance level of 0.1, a higher cost-coverage ratio was associated with a lower level of water losses. That is, financial efficiency was likely to be inversely associated with system inefficiency. A utility that had more assets and less debt was likely to have more financial resources to deal with water losses. The sizes of debt and assets had relatively large and statistically significant impacts on water losses.

Consistent with the AWWA finding that a utility that charged its residential customers higher water rates was likely to have more water losses, the RFC model found that a utility with higher water rates for industrial customers was unlikely to attempt to improve system efficiency, which led to a higher percentage of water losses. Water bills usually consist of two distinct components: one is a changeable portion according to the volume of water used, and the other is a fixed portion related to other services such as connection and system development.[68] While water rates are more associated with the former, the monthly minimum or service charge is associated with the latter. The minimum charge represents stable revenue for a utility because it is not related to the amount of water delivered or lost, so it is not associated with the lost revenue caused by water losses. Thus, a higher minimum charge for customers may strengthen the financial situations of a utility, an important consideration in decisions to invest in improvements to system efficiency. However, this study could not find any strong evidence of a relationship between minimum charge for industrial customers and the percentage of annual water losses. In this sample, the minimum charges for industrial customers were small compared to the water rates for the customers,[69] so it could not have had a significant impact on water losses.

Some water rate structures based on an increasing block tariff or a seasonal/peak-price tariff are more likely to be related to water conservation while a decreasing block tariff is preferable from an efficiency point of view.[70] Since the purpose of a decreasing block tariff is to promote more water use, setting up decreasing block is not advisable from the standpoint of water conservation. Not surprisingly, therefore, this study found that a utility that established a rate structure for non-residential customers based on a decreasing block scheme was more likely to experience more water losses.

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[68] Gracia et al. (2001)

[69] The median monthly service/minimum charge for industrial customers was $58.18 while the median monthly water charge for the same customers was $11,293.55.

[70] According to Gracia et al. (2001), a decreasing tariff scheme is more economically beneficial to utilities, an increasing block scheme is preferred from the standpoint of equity, and a seasonal or peak-price tariff is set up to promote environmental protection. The increasing block rate and the seasonal rate are usually considered important practices for water conservation.

As discussed in H24, a water utility depends on purchased water as a primary water source when water resources are not available or when the cost of developing new water sources are too high. Moreover, utilities that purchase water from other utilities are less likely to consider water as a free good. Water itself is free to most water utilities that withdraw water from the environment even though it requires investment to withdraw and deliver, so a utility that purchases more water from other utilities is more likely to attempt to reduce water losses, proved by this study at the marginally significance level (>0.1). As most western states are facing serious water shortages because of low precipitation levels, water utilities in the western states are likely to be more sensitive to water losses and take action to combat them. The results from the RFC model identified a clear relationship between being located in the West and water losses, which was consistent with the results from the second AWWA model.

Results of the EPA Dataset

The EPA dataset was utilized for three different models for several reasons. The first model used water losses per mile as a dependent variable to check the credibility and consistency of the previous results. While water losses per mile or the percentage of losses are more strongly related to organizational or engineering efficiency, total water losses can be more vital information from standpoint of water conservation. Thus, the second model used water losses as total gross and in the last model, log (water losses) was analyzed to reduce the problem of scale and to find more information.

Table 14. Description of the Variables in the EPA Model

Dependent Variable	
Loss/Mile	Total annual water losses / Total pipe mile (MGY/Mile)
Loss_Gross	Total annual water losses (MGY)
log(Loss)	log(Total annual water losses, MGY)
O&M Factors	
log(O&M)	log(operating costs in the last year, not includes employee expenses), in dollars
log(production)	log(Total annual water production) in MGY
Production	Total annual water production, in MGY
Pipe mile	Total length of the main pipe (miles)
Efficiency	Total water deliveries(MGD) / Total employee number
Connection/Mile	Total connection number/ Total pipe mile
Deliveries/Mile	Total water deliveries(MGD) / Total pipe mile
Pipe_40yr_%	Percentage of the pipe length less than 40 years old
Pipe_80yr_%	Percentage of the pipe length more than 80 years old
Replaced_10	Replaced pipe with greater than 10" (miles)
Repalced_6_10	Replaced pipe with greater than 6"& less than 10" (miles)
log(Replaced)	Total length of pipe replaced in the last 5 years (miles)
Pipe_6	Total length of pipe with less than 6" (miles)
Internal Factors	
Residential Bill	Average annual bill for a residential customer
Conservation_R	Increasing block rate + Peak period rate
Distribution_Ex	Expenditures on distribution system in the last five years ($000,000)
Treatment_Ex	Expenditures on treatment in the last five years ($000,000)
Expansion_Ex_%	Expenditures on system expansion / Total capital expenditure, in the last five years (%)
DWSRF_%	Percentages of capital expenditure funded from total DWSRF (%)
G_DWSRF_%	Percentage of capital expenditures granted from DWSRF (%)
B_DWSRF_%	Percentage of capital expenditures borrowed from DWSRF (%)
B_Public_%	Percentage of capital expenditures borrowed from Public sectors (%)
Nodebt	1 if a utility has no debt, 0 otherwise
Cost Coverage	Total revenues/ Total costs
Connection Ratio 1	Residential connection/ Non-residential connection
Connection Ratio 2	Residential connection/ Total connection
All Metered	1 if a utility has a 100% metering rate, 0 otherwise.
Lowincome_A	1 if a utility employs assistance for low-income customers, 0 otherwise
Bill_Profit	Interaction term created by multiplying residential bill times profit owner
External Factors	
Profit	1 if a utility has profit ownership, 0 otherwise
Purchased Water	1 if purchased water is a primary source, 0 otherwise

As seen in Table 14, the EPA dataset provided a variety of O&M and internal factors but few external factors. Given that the state identifier was concealed for privacy reasons, the EPA dataset could not be combined with other data, which limited the explanatory power of external factors. However, numerous other factors provided very interesting results.

As seen in Table 15, the results of the first three O&M variables were as predicted or consistent with the other results. That is, a utility that had higher water production or operated in a higher service density was likely to experience more water losses while a utility that had younger system lines was likely to experience fewer water losses. The number of service connections per mile is another variable that represents a service density even though it is slightly different from the population served per service area because the number of people served by one connection can vary. However, the differences are usually very small in residential connections and somewhat larger in non-residential connections. In this model, the number of connections and population served were significantly correlated with a linear relationship, so this result seems to match the results from the first AWWA model.

At a significance level of 0.1, operational efficiency was likely to increase the quantity of water losses, which was inconsistent with the previous results and contrary to the expectation in H_7. However, the result found only marginally strong evidence of a positive relationship between the operational efficiency and the level of water losses in the distribution systems.

Table 15. Results of the EPA Model (Loss/Mile)

Linear regression					Number of obs = 436 F(14, 421) = 6.78 Prob > F = 0.0000 R-squared = 0.3600 Root MSE = .18645		
Loss/Mile	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval		Beta
log(Production)	.0838883	.0326222	2.57	0.010	.0197657	.148011	.3843289
Connection/Mile	.0168162	.0063595	2.645	0.008	.0043158	.0293165	.3926253
Pipe_40yr_%	-.0008019	.0003071	-2.61	0.009	-.0014056	-.0001982	-.107769
Efficiency	.0006018	.0003186	1.89	0.060	-.0000244	.001228	.2179055
log(Operation)	-.1003644	.0374203	-2.68	0.008	-.1739183	-.0268104	-.4096774
Conservation_R	-.0351032	.0207174	-1.69	0.091	-.0758257	.0056192	-.0671645
Residential Bill	.000132	.0000606	2.18	0.030	.0000129	.0002512	.0788628
Distribution_Ex	-.0006243	.0004005	-1.56	0.120	-.0014115	.000163	-.0760129
Treatment_Ex	.0025296	.0007022	3.60	0.000	.0011493	.0039099	.2362571
G_DWSRF_%	-.0006778	.000347	-1.95	0.051	-.0013596	4.27e-06	-.0333125
B_DWSRF_%	.0015181	.0009908	1.53	0.126	-.0004294	.0034656	.103077
Bill_Profit	-.0001819	.0000828	-2.20	0.029	-.0003447	-.0000191	-.0783674
All Metered	.0521505	.0195739	2.66	0.008	.0136759	.0906252	.0992004
Lowincome_A	-.0004848	.0248697	-0.02	0.984	-.0493691	.0483996	-.000644
_cons	.297454	.1243215	2.39	0.017	.0530858	.5418223	

Most of the results from the internal variables were not surprising. While higher residential bills were likely to contribute to more water losses, utilities that spent more on operations and employed a conservation-oriented rate structure such as increasing block rate or peak period rate were likely to reduce water losses as discussed before. Since expenditures on distribution systems included replacement and repair costs, they would have a negative impact on water losses. However, this sample did not provide strong evidence for this impact. Expenditures on treatment are typically related to water quality. Given the limited information about water quality, expenditures on treatment could be a proxy variable for water quality. However, results were contrary to the expectation in H_8. That is, the issues of water quantity and quality did not appear to be complementary, but instead led to competition for resources. That is, a utility that invested more on treatment to improve water quality might have fewer resources to invest in other problems, including water losses.

The Drinking Water State Revolving Funds (DWSRF) provides federal loans through the states for water and wastewater infrastructure projects. Even though the biggest source of funds for capital investment is current revenues[71], the relationship between DWSRF and water losses is important for policy implications. That is, it may answer questions pertaining to the effectiveness of public funds, especially federal funds. The DWSRF is generally awarded in the form of grants or loans based on a point system that measures technical, managerial and financial capacities and other relevant features of utilities. Grants from the DWSRF will help a utility improve the system efficiency, including water-loss control, which was proved by this study. However, loans from the DWSRF did not appear to affect water losses. On the contrary, they may actually increase

[71] According to the EPA dataset, 57.12 percent of total funds for capital investment came from current revenues and only 6.34 percent was funded by the DWSRF (1.92 % from a DWSRF grant and 4.39% from a DWSRF loan).

water losses because a loan, with interest, represents debt. In other words, loans from the DWSRF would not be considered additional funds, and thus, like typical debt, would lead to water losses.

Contrary to expectation discussed in H_{13}, a higher rate of metering was not associated with a low level of water losses. Since the U.S. water systems have a relatively high level of meter readings but a low level of meter inaccuracy, meter accuracy seems more important in controlling water losses than a metering rate. So, meter inaccuracy may be the reason that water utilities with a 100% metering rate have higher level of water losses. The results show that there was no statistically significant relationship between efforts of customer assistance and the level of water losses. Consistent with the previous results using the AWWA dataset, an interaction term created by multiplying a dummy variable of profit owner times a continuous variable of residential bill had a negative impact on water losses.

The EPA dataset provides only little information about external factors. One of the external factors is profit – utilities owned privately and operated for profit primarily as a water business, not including homeowners associations, non-profit cooperatives, or mobile home parks. Instead of the interaction term, another model included the variable of profit and found significant negative relationship between profit ownership and the level of water losses.

The second model that used the EPA dataset focused on the total quantity of water losses. Since the total quantity of water losses was directly related to size factors, the R-squared of this model was very high compared to that of the other models in this study.

Table 16. Results of the EPA Model (Loss_Gross)

Linear regression					Number of obs = 449 F(12, 436) = 90.86 Prob > F = 0.0000 R-squared = 0.8250 Root MSE = 1734.6	
Loss_Gross	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval	Beta
Production	.075369	.0033482	22.51	0.000	.0687883 .0819497	.8524525
Pipe Mile	.0696149	.0327832	2.12	0.034	.005182 .1340477	.1438067
Connection/Mile	32.2945	19.98395	1.62	0.107	-6.982349 71.57134	.0334284
Pipe_80yr_%	14.4409	8.305969	1.74	0.083	-1.883822 30.76561	.0505365
Replaced_10	-5.753998	3.139941	-1.83	0.068	-11.9253 .4173047	-.2012189
Repalced_6_10	5.81143	3.361983	1.73	0.085	-.7962792 12.41914	.2375721
Efficiency	-1001.91	518.6942	-1.93	0.054	-2021.362 17.54203	-.0938006
Expansion_Ex_%	-4.443601	1.85825	-2.39	0.017	-8.095844 -.7913591	-.0389245
DWSRF_%	2.180283	1.310312	1.66	0.097	-.39503 4.755597	.0109036
Cost Coverage	.6646272	.3059019	2.17	0.030	.0634015 1.265853	.0075974
Connection ratio 1	-.011817	.0055027	-2.15	0.032	-.0226321 -.001002	-.0699358
Purchased Water	-136.3744	102.0012	-1.34	0.182	-336.8495 64.1008	-.0161873
_cons	-37.99005	209.2556	-0.18	0.856	-449.2651 373.285	

Many variables in the EPA dataset were significantly correlated with total production, so these variables could complicate the relationship with water losses. To avoid this complication, the first step for the analysis was to identify the size factors. This study assumed that when the correlation between total population and a variable was statistically significant at a significance level of 0.05 and the value of the correlation was greater than 0.5, the variable was considered as a size-related factor. Except for total production, all these size-related variables were dropped from this model.

All the results from the O&M factors were as expected. The impact of total production, pipe miles, connections per mile, operational efficiency, and pipe age on the total quantity of water losses were consistent with the previous results at a marginally significant level (>0.11). The differences in the signs of the coefficients for two variables of the replaced pipe length with a different diameter could be explained by pipe size. Large-diameter pipes seem a more effective target for water-loss control. Because the failure of large-diameter pipes causes more damage and leads to higher costs, and also the damage to such pipes can be detected more easily, utilities are more likely to focus on large-diameter pipes than small-size pipes, which may lead to the better management of large-diameter pipes and the relatively poor management of small-diameter pipes. That is, large-diameter pipes are likely to have a smaller failure rate than small-size pipes, which reduces the total quantity of water losses. In the sample, small-size pipes, among the replaced pipes from 1995 to 1999, seemed to have problems such as leaks and breaks, which contributed to more water losses. At a significance level of 0.1, this study confirmed that utilities, through the more effective management practice of replacing large-size pipes, had reduced the amount of lost water.

More expenditures on expansion typically indicate growing water demand, so the relationship between expenditures on expansion and water losses is likely to be negative, which was proven by this model. The utilities in this sample received more DWSRF loans than grants, so the impact of total DWSRF on water losses would be the same as that of the DWSRF loans, which could explain why total DWSRF had a negative impact on water losses. The relationship between cost coverage and water losses and the relationship between customer mix and water losses in this second EPA model were odd and inconsistent with the other results. Connection ratio 1 was the ratio of residential connections to non-residential connections. Since residential customers use much less water per account than non-residential customers, residential customers are served by smaller-size pipes that are often managed less effectively than larger-size pipes. Hence, the result was unpredicted and inexplicable.

As proven in the RFC model, a utility that used the purchased water as a primary source was likely to reduce water losses, but this model could not find strong evidence supporting the various effects of water source types.

Since the dependent variable of the second EPA model was a relatively large number with a range from 0 to 55,986, this model should consider the scale issue. To reduce the scale problem, support the previous results, and find additional information, the last model used a log function in a different framework.

Most of the results in Table 17 were consistent with the other results, and all of the results were statistically significant at a 0.05 significance level, so only new variables were explained here. Pipe_6 was the total length of small-size pipes, and as discussed before, small-size pipes were likely to be poorly managed, which resulted in more water losses. In this sample, most replaced pipes were small-size (less than 10") and only 10.3 percent of the replaced pipes were large-size, so the impact of the length of total replaced pipes was likely to represent small-size pipes. Therefore, it followed that the more small-size pipes a utility replaced, the more water losses it would incur. The variable of deliveries per pipe mile confirmed the different effects of pipe diameter.

Table 17. Results of the EPA Model (log(Loss))

Linear regression						
				Number of obs = 512 F(9, 520) = 91.72 Prob > F = 0.0000 R-squared = 0.5619 Root MSE = .85292		
log(Loss)	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval	Beta
log(Production)	.776169	.0562273	13.80	0.000	.6656991 .8866389	.6699915
Deliveries/Mile	-.3541821	.0663998	-5.33	0.000	-.4846378 -.2237264	-.0533654
log(Replaced)	.133093	.0530058	2.51	0.012	.0289525 .2372336	.0990499
Pipe_6	.0000195	7.56e-06	2.58	0.010	4.63e-06 .0000343	.0647771
Efficiency	-3.482576	.1764944	-1.97	0.049	-.6950163 -.0014989	-.1069387
Nodebt	-.2183316	.0938792	-2.33	0.020	-.4027761 -.0338871	-.0724839
G_DWSRF_%	-.0061967	.0026993	-2.30	0.022	-.0115001 -.0008934	-.0507999
B_Public_%	-.003962	.0019999	-1.98	0.048	-.0078913 -.0000328	-.0628819
Connection ratio 2	.4084233	.2052267	1.99	0.047	.0052142 .8116324	.0758946
_cons	-1.262251	.226999	-5.56	0.000	-1.708199 -.8163033	

To deliver more water per mile, a pipe must be large, so more water was delivered through large-size pipes when the deliveries per mile increased. That is, the negative sign of the coefficient confirmed that large-size pipes were likely to be managed properly, which led to the lower level of water losses.

As discussed before, a utility whose capital investment was 100% funded from current revenues was likely to have less lost water. However, a utility that borrowed more and more funds from public sectors such as state or regional authorities was likely to reduce water losses even though these funds had to be paid back with interest. The interest of public loans was much lower than that of private loans, and state governments might have more preferable loan systems for water utilities than federal governments. Connection ratio 2 was the ratio of residential connections to total connections, which was very similar to connection ratio 1. As discussed above, a utility that had more residential connections compared to other customer connections was likely to delver water through small-size pipes, which led to more water losses.

Summary of the Findings

This study was designed to provide a comprehensive and complementary framework to identify the factors that influence the level of water losses and estimate the strength of their impacts based on the same conceptual model (Figure 3), which yielded significantly consistent results from several different practical models with three different datasets. By testing the hypotheses, this study confirmed the importance of several well-known factors and identified several new key factors that determined water losses.

As predicted, O&M factors had the most significant impacts on water losses. In particular, system size, represented by total production or population served, and infrastructure rehabilitation were crucial factors. The effects of system rehabilitation varied according to pipe diameter, and large-size pipes seemed to be better managed. The positive effects of system age and service density on water losses were consistently confirmed. This study found strong evidence that the level of water losses was influenced by O&M costs. That is, routine O&M seemed to include water-loss control. Operational efficiency, although logically, a good determinant, was not consistently confirmed by this study. Water quality and quantity issues seemed to compete for resources, so it would be hard to reach both goals simultaneously due to resource limitations. Water utilities were unlikely to take immediate actions against the system failure, which might cause a considerable problem for the control of water losses.

The effects of some internal factors on water losses were predicted but those of several internal factors were rather unclear and relatively complicated. This study could not find any consistent impact of customer mix, cost coverage ratio, and debt on water losses, but it did provide possible explanations for the inconsistent results based on different situations. Employees were important resources to reduce water losses even though it is a size-related factor. A utility that implemented conservation practices such as water conservation-oriented rates was more likely to improve its system efficiency. This study consistently found that utilities had motivation to recover revenue losses by raising water prices. The size of assets seems to be a good determinant of water losses. And the capital expenditures and funding sources could be explanatory variables for the level of water losses.

This study confirmed that utilities were more likely to be motivated to combat water losses if certain external conditions, such as higher water demand, limited resource availability, and institutional pressure exist. Different types of water sources might be determinants of water losses. This study also found that private owners dealt more effectively with water losses than public owners.

In most cases, the signs of the coefficients for the same variables were consistent, but the strengths of the coefficients were not comparable. The AWWA dataset and the EPA dataset were based on the same dependent variable (loss/mile) and shared two important independent variables such as log(production) and residential bill. Both used the same unit and samples were selected from throughout the country, but the survey time differed by four years and the sample sizes differed almost by 4 times. Water bills in the AWWA sample surveyed in 1996 were slightly lower, but the survey included larger-size water utilities, which resulted in extremely different mean values of the dependent variable. Nevertheless, this study successfully identified a variety of factors that determined the level of water losses and estimated the relative strength of their impact, which will allow the identification of policy implications and recommendations for water utilities.

CHAPTER 5

FINDINGS OF THE CASE STUDIES

To identify the factors that affect management's decisions over the adoption of proactive water-loss management, this study conducted case studies based on a survey and combined the results with the 2002 AWWA dataset that provided extensive distribution system data. The major purposes of the survey were to explore managers' perceptions about the adoption of water-loss management and several issues related to water losses, and to identify organizational characteristics that may influence management's decisions to adopt such strategies. The AWWA dataset provided in-depth information of cases of water losses, including those resulting from general, infrastructure, O&M, water-loss management, and other factors. Even though the information from the survey and the data from the AWWA were collected at different times[72], this was not considered problematic inasmuch as changes in both managers' perceptions and organizational characteristics were not usually dramatic or abrupt. To obtain additional insights, this study included the results from a survey by Beecher (2002) that provided information about institutional pressure on water losses. This chapter discusses the findings of the case studies, and includes general information about the

[72] The AWWA survey was conducted in 2002, and the survey data conducted by this study was based on 2004 even though this survey was conducted in 2006. Most of data about the distribution systems came from the AWWA dataset unless specified, but all perception-based data came from the survey conducted by this study.

participants of the survey, followed by managers' perceptions, organizational characteristics, and finally a summary of the findings.

Participants of the Survey

The target participants of this study included 76 utilities contacted by mail or/and emails: 43 in the focus group and 33 in the control group. A total of 19 utilities participated in this survey: 11 from the focus group and 8 from the control group. The response rate was approximately 25% in each group. However, since the information used to categorize the potential survey participants into two groups was based on the 2002 data, the demarcation of the focus group and the control group was misleading. The six participants among the control group have already implemented proactive water-loss management in 2006. Obviously, most of the participants were utilities that were actively dealing with water losses, so any comparison between the two groups would be of no consequence. Therefore, this study explored the results from a focus group of only 17 utilities.

As designed, most of the respondents were managers or directors who had the authority to make management decisions including the adoption of proactive water-loss management. The participant utilities were from 13 states and six of which were from western states. Five utilities had experienced periodic supply constraints due to drought, withdrawal restrictions, system capacity limitations, or other conditions. The participants were all publicly-owned utilities. Based on the population served, one participant was a small-size utility, eight were medium, and the other eight were large.[73] From 1990 to 2000, the average population increase of the cities that the utilities served was 15%. They averaged 55,103 miles of service lines with a range from 3,616 to 474,577, and served roughly four people per mile. In addition, 99.63% of the service lines were metered, and five of the utilities read over 50% of their meters by using Automatic Meter Reading (AMR) equipment instead of meter readers. Eleven utilities had a regular meter testing program and they reported that their customer meters averaged a 2.65% under-registration error while the utilities in the AWWA dataset averaged 3.82%.

In 2001, they laid on an average of 11.84 miles of new pipelines for main extension, main replacement, cleaning and lining, slip lining, pipe bursting, cured-in-place popping, horizontal directional drilling, and customer service line replacements. Six utilities reported that they needed additional infrastructure renewal and rehabilitation activities to sustain effective water supply operations over the next 20 years. The cost coverage rates of all 12 utilities that provided the financial data were over one. That is, they were financially efficient. The participant utilities increased their water rates by 6.25% over a five-year period (from 1999 to 2004) while the utilities in the RFC dataset increased their rates by 4.3% annually.

In 2002, the average percentages of total revenue water and the total water losses of the 17 utilities was 89.4% and 10.6%, respectively. However, in 2004, the average percentages changed to 88.19% and 7.4% based on the 14 utilities that provided water audit data. The managers of the 17 utilities considered aging infrastructure as the major

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[73] Small systems served less than or equal to 10,000 people; large systems served over 100,000 people; and medium systems were between the small and the large systems.

cause of water losses, followed by meter inaccuracy and unavoidable leakage. They estimated in 2002 that an average 19.35% of all input meters did not accurately measure water input to the distribution system. During 2002, the 17 utilities found 99 main breaks and 509 leaks, and repaired 72% of the breaks and 85% of the leaks, but in 2004, they answered 97.5% of the reported breaks were repaired. The average time that customers of the 17 participants were out of service due to breaks was 3.5 hours while the average time of all the utilities in the AWWA dataset was 4.1 hours.

Most utilities held the ownership and the maintenance responsibility for the customer service lines between the water main to the "curb stop and box," but only 10% of the utilities owned and maintained customer service lines beyond customer meters or premises if no meters existed. Seven of the seventeen utilities operated a customer assistance program to aid leak repairs, such as low interest loans, grants, or insurance that customers could purchase while only 26% of the utilities in the AWWA dataset provided such a program. In 2004, the average duration that leaks existed before they were repaired was 8.2 days for the 17 utilities.

While seven utilities provided a water-loss reduction target as a percentage value with a range of 6% to 15%, two utilities set their targets as the total amount or the number of leaks. In 2002, the eleven utilities spent an average of $107,263.60 on proactive water-loss management. While only six of the 17 utilities claimed that they knew that their state or other agency required them to address water losses and loss-reduction, according to the survey by Beecher (2002), 13 of these utilities were actually in states that required accounting and reporting.

Managers' Perceptions

To identify the motivators of the adoption of proactive water-loss management directly, this survey asked managers why they initiated proactive practices. As shown in Figure 4, seven of the eleven utilities admitted that the high level of water losses was the most important reason that they initiated proactive water-loss management. Other important reasons were financial pressure, leadership, state requirements, and limited water supplies. However, six utilities said that limited water supplies did not enter into the decision to initiate active water-loss management because they did not experience any supply constraints. According to the managers, grants or financial support also were not motivators perhaps because few grants had been awarded specifically for the purpose of water-loss control. Thus, the severity of a problem, financial crisis, leadership, and institutional pressure were factors that are highly related to the adoption of the proactive management.

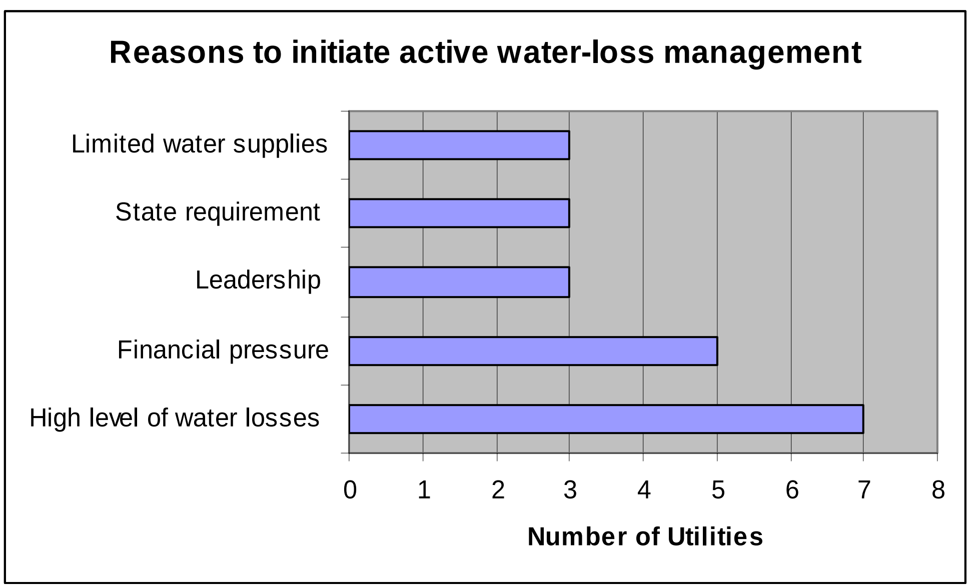

Figure 4. Reasons Why Utilities Initiate Active Water-Loss Management

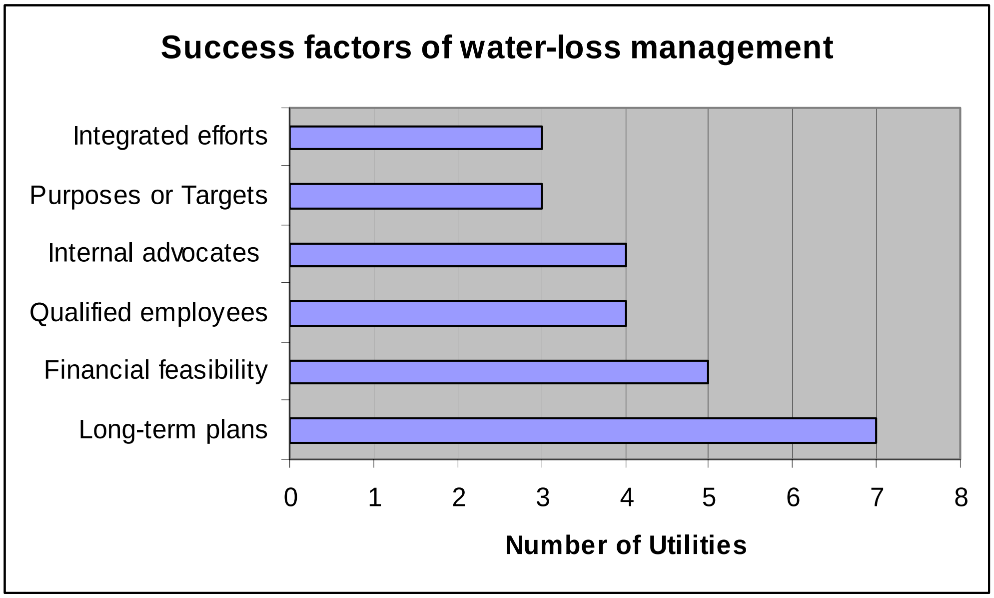

Figure 5. Factors Associated with the Success of Water-Loss Management

Seven of eleven utilities emphasized the importance of long-term plans for successful water-loss management, and five of them selected financial feasibility as the most important success factor. Managers from all the utilities considered qualified employees important (very or a little). Internal advocates along with target-setting and integrated efforts were the most important success factors to some utilities. External financial, political, or public support, legal obligations, and technical assistance or technology feasibility seemed insignificant to the success of water-loss management. The most important criteria for evaluating the success of the management were saving production costs and increased revenues. All the utilities evaluated that passive water-loss control, repairing reported leaks, was successful in terms of saved water and revenues. Even though some utilities did not evaluate all the programs, several practices evaluated by the utilities were proven successful, such as an active leak detection/repair, a regular metering test, a system-wide meter upgrade, and an accounting/ billing test program.

Some utilities proved that pressure management, theft-control, energy-conservation, and water conservation programs did not save production costs or increase revenues.

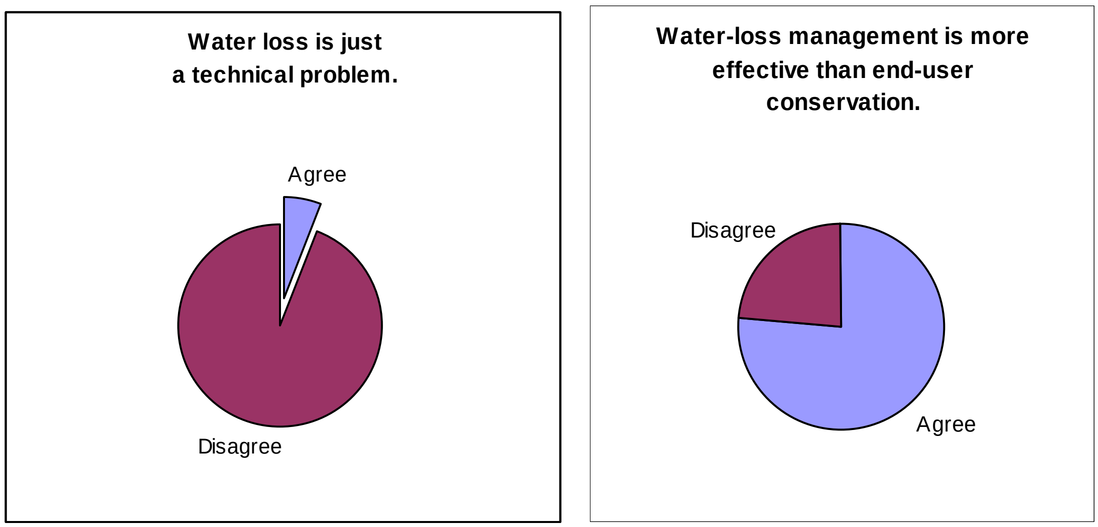

Figure 6. Managers' Perceptions on Water Losses and Water-Loss Management

All the utilities except one were tracking water in the distribution systems and considered the amount of water losses as an indicator related to system efficiency. The managers did not consider water losses a simple technical problem and they agreed that water-loss management was more effective than end-user conservation. Although they did not expect strong institutional pressure on water losses, many of them included water-loss management in their conservation programs and even in water resource management.

Organizational Characteristics

Organizational structure and culture were not easy to measure, so this survey identified organizational characteristics that might influence the adoption of proactive water-loss management based on managers' perceptions on their organizations. Out of the 17 utilities, 14 allowed employees to participate in decision-making processes, and 12 seemed to reduce structural complexity by defining clear roles and responsibilities. A majority of managers considered their organizations homogeneous, and eight allowed flexibility on funding allocations, which would reinforce organizational decentralization.

Centralization (manager)	8	9	Decentralization(manager)
Heterogeneity	6	11	Homogeneity
Less Participation	3	14	More Participation
Complexity	5	12	Simplicity

Figure 7. Internal Factors Associated with the Adoption of Water-Loss Management

Fourteen utilities averaged 240 employees, approximately 15% of whom were certified employees. Fifteen utilities, with an average of five departments in their organizations, revealed that an average of 113 days was needed to approve a new proposal for system improvement. Many utilities seemed to have a positive outlook on the future and good performance in production, inter-government relationships, customer service, and system efficiency. Despite the lack of personal and organizational incentives for making changes, they attempted to be ready for the future. However, more managers were willing to share information with the public rather than involve them in decision-making processes. The major problems for the utilities were water quality and aging infrastructure, rendering water losses less important.

Although most managers claimed to be leaders in the water industry, they seemed to depend on outside networks for their information. The most important sources of information were water associations such as the AWWA, the AMSA, the AMWA, and other regional associations. They also considered employees as very important sources of information and valued their participation. Most utilities also obtained important information through governments and workshops. Interestingly, the water utilities did not seek information from environmental organizations or universities. Figure 8 shows that a variety of sources of information the water utilities depend on.

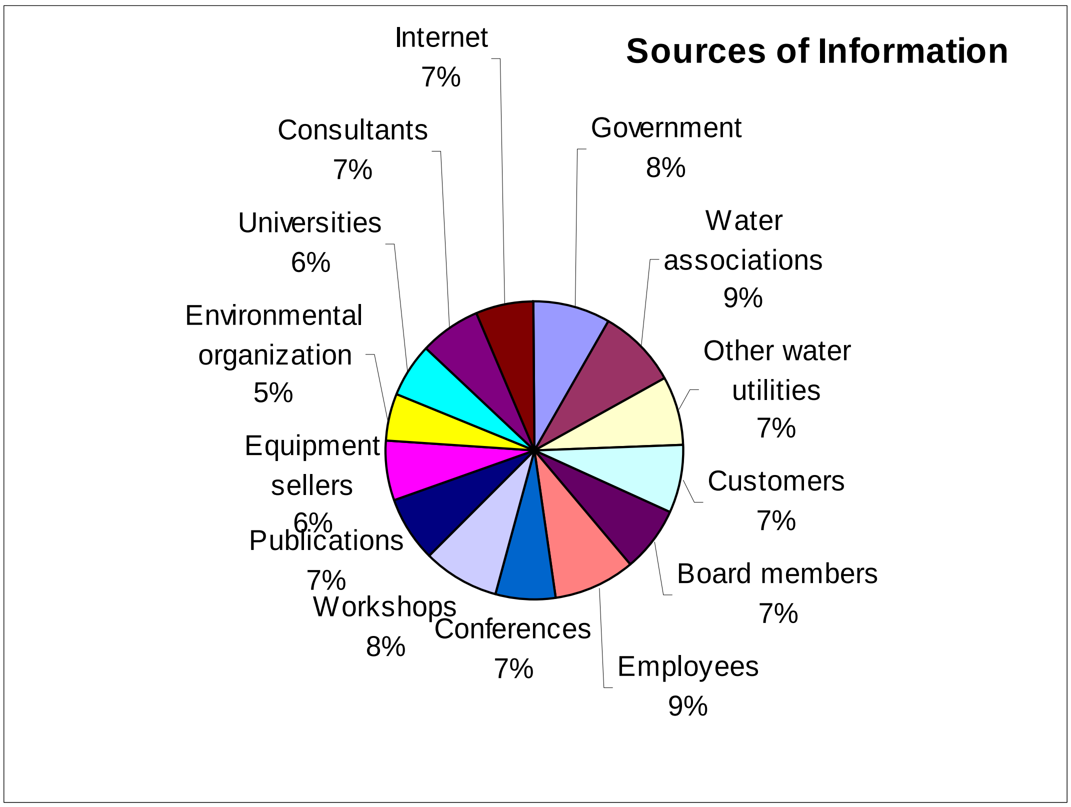

Figure 8. Sources of Information

Summary of the Findings

This survey confirmed the previous studies conducted by innovation researchers. As discussed in Chapter 2, both internal and external factors were likely to influence managements' decisions to adopt proactive water-loss management. The perception-based data provided by managers found that utilities were likely to implement water-loss management when they faced population growth, severe problems, financial crisis, and institutional pressure related to water losses, and when the organizational culture reinforced less complexity, more homogeneity, strong leadership, and active employee participation.

Since no comparative data were available, this study could not evaluate the impact of organizational size or clear regional differences. The data about slack resources, professionalism, and risk of innovation were difficult to obtain, so they were not included in this study. The utilities that were studied seemed to have developed an active social network, but they did not seem to consider external financial or political support as important motivators or success factors. In addition, technical constraints did not appear to hinder the utilities as managers did not considered them significant.

This study found several internal and external factors associated with the adoption of proactive water-loss management; however, as expected, internal factors seemed to have more significant impact on the managements' decisions over such adoption. The utilities that had already adopted proactive management showed strong performances in a variety of fields, including system efficiency, customer service and assistance, and public relations. Thus, to improve their performance, utilities should create, promote, and reinforce an innovation-friendly organizational structure and culture.

CHAPTER 6

CONCLUSIONS

The purpose of this study was to assist policymakers and water utilities with developing strategies for proactive water-loss management by identifying the factors that determine the quantity of water losses and those that factors that influence the adoption of the proactive management. As discussed before, water losses are the results of a number of O&M. Most of these internal factors, which are related to the capacity of utilities to manage their organizations, customer relations, financial plans, and public relations, call for strategic system improvements. Related to these internal factors are governmental frameworks that provide the contexts in which utilities operate reinforce the capabilities of the utilities. Even though water utilities often attempt to improve system efficiency when they confront supply constraints or increased water demand, the external factors are usually beyond the control of most utilities, resulting in passive responses. Thus, governments have more responsibility for managing the external factors.

The utilities that have already adopted proactive water-loss management seem to be more amenable to adopt new practices because they have certain characteristics and their managers have more positive perspectives. As a consequence of the lack of strong institutional pressures on water-loss control, some of the external factors do not seem to have a significant impact on managements' decisions to adopt proactive management practices. However, many external factors are important in that they provide information and opportunities that encourage the adoption of new practices. Referring to the results of data analyses and case studies, this chapter discusses policy implications and recommendations for the water industry, limitations of this study, and suggestions for further studies.

Policy Implications

One of the most interesting findings of this study is that the current institutional framework can provide an incentive for utilities to recover revenue losses resulting from the inefficient management of their systems by raising water rates rather than by improving system efficiency. The results of this study consistently confirm that utilities with more water lost in their systems charge their customers more than utilities with low level of water losses, which implies that water utilities transfer the costs of system inefficiency to customers. Especially, public-owned utilities that win water rate approval easily seem to attempt to recover revenue losses by increasing water bills. Thus, processes for approving water rate increases should be reevaluated in terms of system efficiency. The financial difficulties and needs that are the primary considerations for approval should be analyzed according to the causes. However, such an approach is not feasible when information asymmetry between public service commission and utilities is great.

Even though some states have required water utilities to implement accounting and reporting of water losses, most states do not require compilation and publication of information about water losses (Beecher, 2002). That is, information about water losses is not shared with the public. Even in the states that require reporting, processes for auditing and enforcement of water-loss regulations have not been established, nor do they provide a clear definition of water losses.[74] Therefore, the quality of the information is questionable. That is, the current regulations do not reduce information asymmetry

[74] Beecher (2002)

between water utilities and regulators, public service commission, governing boards, or the public. Therefore, regulations should be revised so that they promote the sharing of information with all stakeholders and ensure the quality of the information.

This study confirms that water losses can be reduced though institutional pressure. As discussed in Chapter 4, the most stringent regulations have proven effective in reducing water losses. On the 2002 AWWA survey, utilities were asked if any state or other agency required that they address water losses and loss-reduction. Some of the utilities in 23 of the 44 states surveyed answered that they had a certain degree of requirements related to water losses, but interestingly, other utilities in the same states answered that they did not have any requirements. These conflicting views may have stemmed from differences in the sizes and districts of the utilities, but in cases in which sizes were similar or districts were the same, they may be stemmed from unclear definitions or requirements for water losses. Inconsistent terminology used for "water loss" could be blamed for confusing regulatory requirements. Furthermore, regulatory targets that are set too high may hinder proactive water-loss management in some state, and targets are recommends, not mandatory in most states. Thus, water-loss regulations should be more stringent and "water loss" more consistently defined.

Water conservation is crucial in fostering not only environmental protection but also sustainability of water provision. So, a variety of water conservation practices have been implemented throughout the country, including water conservation-oriented rates. Because of revenue volatility and other economic and managerial reasons, many utilities do not prefer practices such as increasing-block rates and peak-period rates; instead, they have implemented flat, uniform, or decreasing-block rates. However, this study finds that utilities that employed conservation-oriented rates have less lost water in their systems. That is, conservation-oriented rates foster supply-side as well as demand-side conservation by emphasizing the importance of efficient water use and management, which indicates that conservation-oriented rates may prove more economical. Thus, water policy should promote implementation of conservation-oriented rates in the more comprehensive framework of water conservation.

A large amount of capital investments in water utilities comes from government funding, and the Drinking Water State Revolving Funds (DWSRF) is one of the major source of federal funds for the water industry. However, this study found that the types of funding (i.e. loans or grants) had a different impact on water losses. While grants from the DWSRF help a utility improve system efficiency, loans from the same source may not. However, loans from states or other governments are useful for the improvement of system efficiency. Given the broad range of interests and the amounts of loans, it is difficult to identify the reasons why loans from the DWSRF contribute to increased water losses. Thus, more intensive investigation into its system along with interest rates is needed to evaluate the efficiency and effectiveness of the DWSRF grants.

Another finding of this study is that among the various problems endemic to highly-populated societies, water losses in the distribution system are no exception. As water is a vital public service, planners tend to consider the capability of water provision, but inefficient water deliveries are not considered in planning processes, which may distort the planned capability of water supplies. Because service density influences water losses, estimation of the appropriate degree of service density is vital not only from the perspective of decision-makers and planners but also from the standpoint of water conservation.

In the absence of strong institutional pressure to decrease water losses, the utilities that have adopted proactive water-loss management seem to have a goal of improving organizational performance. Neither external funding nor political support is very important to these early adopters, but governments are important as they are major sources of information. Thus, governments should provide more timely information to promote proactive water-loss management practices, and establish institutional frameworks that encourage such practices and thus, increase the rate of adoption.

Recommendations for Water Utilities

The amount of lost water is a good indicator of system inefficiency and correlated with other efficiency indicators such as operational efficiency and financial efficiency. That is, the calculation of water losses should be very useful to utilities that develop strategies to improve performance. This study identifies several important factors that determine the amount of lost water, including system size, infrastructure rehabilitation, system age, service density, O&M costs, employees, assets, liabilities, debt, and capital investment. All of these factors have a strong relationship with water losses, and this study has confirmed widely held perceptions. However, some other factors found in this study can provide insights into water losses.

One such factor is the effect of different pipe sizes, which this study found varied depending on how utilities managed their pipelines. Since the failure of large-size pipes usually causes bigger problem that lead to more lost water, a focus on the management of large-size pipes would be more useful to utilities. Thus, when utilities have limited resources, they can target large-size pipes first for replacement or rehabilitation. However, utilities must also recognize that system efficiency cannot be improved without good management of small-size pipes as well because they comprise a significant part of entire system. Therefore, water utilities should also improve the management of small-size pipes.

Water quality, particularly the quality of drinking water, is typically controlled by stringent regulations, so utilities with limited resources may use the resources to maintain water quality rather than to mitigate water losses. That is, both needs of water quality and water losses seem to compete for limited resources, and it is difficult to effectively allocate resources to both. However, since water losses resulting from system leaks or breaks damage the quality of water delivered to customers, utilities should make efforts to manage both needs complementarily in a more comprehensive context.

Results of this study also show that many water utilities do not repair leaks and breaks in a timely manner. Even though all reported and detected breaks cannot easily be repaired in a short time, they can be repaired in a more timely way, which is an important component in water-loss control. If utilities have too many breaks to handle in a timely way, they do not have sufficient crews for the maintenance of the distribution systems or their systems are reaching the end of their life expectancy, so they must assign more crews to the distribution systems or consider system-wide rehabilitation.

More and more states focus on water conservation and have implemented various conservation programs, and water utilities are often at the center of such programs. Water conservation will be more effective when the supply side and the demand side become integrated. Recently, the new guideline for water conservation includes both-side conservation programs.[75] According to the results, a utility that employs water conservation programs, particularly conservation-oriented rates, recognizes the consequence of efficient water use and attempts to reduce inefficiency of its own supply systems, which intensifies the effects of water conservation programs. Thus, utilities should consider water conservation programs for not only demand-side but also supply-side.

Appropriate water rates are also very important in customer relations. This study confirms that high water rates are related to system inefficiency. If a utility attempts to increase water rates without making efforts to improve overall system efficiency, it will damage customer or public relations, which can make it difficult for a utility to win additional approval for a rate increase. Therefore, water utilities should not transfer losses resulting from the inefficiency of their systems to customers.

External funds are essential for water utilities. However, the source of the funding affects the financial burden of a utility differently. Not surprisingly, grants lead to more improvement in system efficiency than loans. Thus, utilities should consider various funding sources more carefully from both an economic point of view and a performance point of view.

Even though no strong institutional pressure on water losses has been established, this study confirms that if a utility deals with water losses proactively through the adoption of innovative management strategies, it can improve system efficiency and overall performance. Most of the techniques that utilities use to control water losses have

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[75] AWWA (2006)

already proven effective, so the risk of the adopting such techniques is relatively small.[76] Some utilities have already taken advantage of such innovative management, and the organizational characteristics and culture of these utilities should provide useful models. As some states are planning to institutionalize more stringent regulations[77], utilities should follow these models and become more innovative.

Limitations of the Study

Even though this study contributes to the development of strategies for water-loss management, it cautions against generalizing the results of this study due to several limitations. For one, this study depended on secondary datasets, the purposes of which differed from those of this study, which therefore may be limited, due to hidden biases, recording errors, concept differences, and unavailable data. It is difficult to control errors of secondary datasets, so the high level of co-linearity among variables in the models could not be controlled, which the results failed to produce robust coefficients. In addition, some of information from the datasets is out-of-date. Another limitation of this study is that although most the results from the three different datasets were consistent, some were not, which might have resulted from the different setting of the datasets. Furthermore, the samples of each dataset were too diverse to allow for an accurate comparative analysis. For example, this study could not consistently determine how much more water would be lost per 1% increase of total water produced.

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[76] However, this is not always true. For example, some water utilities in the case studies reported that pressure management programs were not successful. However, the AWWARF and other research groups continue to conduct research on better water-loss control programs, which will reduce the risk of innovations.
[77] The state of Washington has a plan to require water utilities to maintain the level of UFW at 10% with strict enforcements (Taylor, 2006).

Although this study attempted to analyze water losses in a nationwide framework, the number of samples was not big enough to generalize the results. The EPA dataset included 917 utilities but only half of them were analyzed in the models, and a comparison of the samples in and out of the models showed some differences. For example, the two sample groups showed different relationships between water losses and total water production and did not overlap the confidence intervals. That is, the missing variables in the EPA dataset may not have been random, and the samples in the EPA models may not have represented the entire dataset. This study utilized linear regression models with different units. Since the linear statistical model assumes a random sampling, the EPA model may have yielded biased results. Due to a few extremes in the data, some of the results could be skewed. Thus, generalization of the results calls for some cautions.

Case studies always limit generalizations of results. This study could not analyze the case studies in a comparison framework because most participants were considered as a focus group. The goal of the case studies is to identify organizational culture and characteristics of the early adopters who are dealing with water losses in a very effective way, and this study does not attempt any generalization from the results but provides some suggests for better management of water losses. The case studies are based on managers' perceptions, so the results may be subjective and biased owing to social desirability biases.

Further Studies

This study is the first research to identify the factors associated with water losses in a comprehensive framework and analyzes the organizational characteristics of innovative water utilities that have implemented proactive water-loss management, so this study can be extended to various other studies. Based on the results and the limitations of this study, this chapter will conclude by suggesting future studies.

Water losses are the results of long-term operations and management, so it will be more appropriate to analyze them in a time-series format. None of the three datasets included consistent panel data but all of them were based on periodic surveys, so intensive data processing may allow a time-series analysis. As the EPA dataset poses a problem with random sampling, it will be useful to analyze it through imputations. Some advanced statistical methods such as multivariate imputation by chained equations (MICE) help find missing information and incorporate more observations in the model, which will be helpful in the generalization of the results.

Although researchers have developed innovation theory based on case studies of various organizations, water utilities have not represented target study groups because of few adoptions of innovations. However, to deal with challenges, more and more water utilities have attempted to adopt innovative techniques and management tools, including proactive water-loss management. Moreover, more stringent institutional frameworks for water-loss issues are about to be established in some areas, so future research on the adoption of innovations in the water sector should lead to the development of innovation theory.

In the public policy arena, some interesting research topics can be generated from this study. This is the first study to identify the relationship between supply-side and demand-side water conservation in a statistical framework. Since the two should be integrated, the further studies on this issue will yield numerous policy implications. Since many water utilities are small, equity issues of large- and small-size utilities should be addressed in water-loss management. As discussed in Chapter 4, small- or medium-size utilities are not dealing with water losses effectively because of limited resources. Thus, any new institutional pressure on water losses will affect these utilities more significantly than large-size utilities, so special consideration for small-size utilities is needed, which can be supported by further studies. In addition, although many studies on water rates have been conduced, relatively few studies have focused on the relationship between rates and system efficiency. However, this relationship is an important topic from a public relations and social responsibility point of view. Finally, to deal with water losses efficiently, the economic level of water losses should be estimated. Thus, the future studies should focus on more comprehensive and standardized water audit formats and methodologies which are able to provide different loss measures such as real, apparent, existing, economic, and unavoidable water losses.,

APPENDIX A

SURVEY QUESTIONNAIRE

Invitation to the Survey

Dear______________,

I am Hyun Jung Park, a doctoral student in public policy in the joint degree program at Georgia State University and the Georgia Institute of Technology. I am doing research on water-loss management and am collecting data on current practices in water-loss control and on factors that encourage or discourage effective practices. All over the country, the problems of water losses have become an important policy issue. However, it is difficult to find good information about how water systems manage water losses, so I am conducting this on-line survey. About 50 water utilities will be recruited for this study and your utility is invited to share your successful stories about water-loss control. Through participation in this survey, you will be a part of an effort to develop policy options and strategies to reduce water losses in the U.S. water systems, which will benefit our society by promoting efficient water management. After finishing this survey, you can access the summary of the survey results and ask a copy of the final report, which may help your utility improve the plans for water-loss control. But, participation in this study may not benefit you personally.

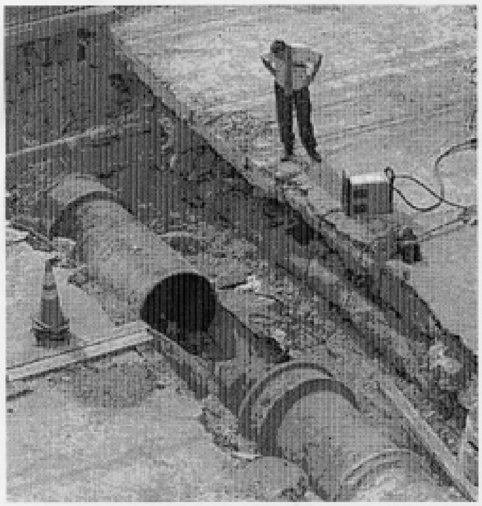
The best person to answer this survey is a manager or employee who deals directly with water losses. The survey questions require some basic system information, some specific data about water losses, and some institutional or organizational factors. You might need documents such as 2004 annual reports to answer these questions and this survey will take between 15 and 20 minutes if you have the report with you. The information you provide will be used for academic research only – all information that might identify your organization or you will be removed in the final results and the data will be kept confidential and stored on a password and firewall-protected computer. We do not obtain any information of your IP addresses. So, in this study, you will not have any risks and if you have questions or concerns about your rights as a participant in this research study, you may contact Susan Vogtner in the Office of Research Integrity at 404-463-0674 or svogtner1@gsu.edu. You can keep a copy of this letter for your records and if you have any questions about this study, please feel free to contact me at 404-697-6787 or gte514x@prism.gatech.edu or Dr. Carolyn Bourdeaux at cbourdeaux@gsu.edu

If you wish to participate in this survey, please click the below link:
http://www.surveymonkey.com/s.asp?A=121180914E47462
Thank you for your assistance.
Hyun Jung Park
Please note: This survey is based on voluntary participations. If you do not wish to receive further emails from us, please click the link below, and you will be automatically removed from our mailing list:
http://www.surveymonkey.com/r.asp?A=121180914E47462

Survey Questionnaire

Please be ready with your 2004 annual report and be careful to follow the units (ex: $1000, gallons, or day) different in each question. If you prefer different units, put the unit with data together in the same cell. Please make sure that all information you are providing is based on 2004 data.

If you are interrupted and cannot finish the survey in the initial sitting, please click on the NEXT button and return to the survey using the same computer. This will allow you to resume where you left off.



Water-Loss Management Questionnaire 1

Your Participation Is Priceless.

Please be ready with your 2004 annual report and be careful to follow the units (ex: $1000, gallons, or day) different in each question. If you prefer different units, put the unit with data together in the same cell. Please make sure that all information you are providing is based on 2004 data.

If you are interrupted and cannot finish the survey in the initial sitting, please click on the NEXT button and return to the survey using the same computer. This will allow you to resume where you left off.

1. Is that you in the picture? The man above is suffering from water loss in the distribution systems. Do you have problems of water loss?

NO	YES

2. Please rate the influence of the causes of water losses in your system.

	1: NOT important	2	3	4	5: VERY important
Aging infrastructure					
Wrong materials or sizes of pipe lines					
Poor operation (high pressure, overflows etc.)					
Poor maintenance					
Meter inaccuracy					
Billing adjustments					
Accidental bursts					
Unauthorized uses (stealing)					
Unavoidable leakage					

3. In 2004, what percentage (%) of the reported leaks and breaks was repaired?

(%)

4. Average duration in days that leaks existed (from reported to repaired) in 2004.

Days

5. If your utility implements the following programs, please specify the name of the department or contractors in charge of each program. If your utility does not implement any of the following, please leave the cell empty.

Water conservation programs	
Energy conservation programs	
Repairing reported leaks	
Active leak detection & repair	
A regular metering test	
System-wide meter upgrade program	
Supply auditing on a regular basis	
Accounting & billing test	
Pressure management to control water losses	
Program for reduction of water theft	

6. Which of the methods has your utility evaluated to be successful?

	Not Successful	Successful	Never Evaluated
Water conservation programs			
Energy conservation programs			
Repairing reported leaks			
Active leak detection & repairs			
A regular metering test			
System-wide Meter upgrade program			
Supply auditing on a regular basis			
Accounting & billing test			
Pressure management to control water losses			
Programs for reduction of water theft			

7. What is the basis for determining success of ACTIVE water-loss management: such as active leak detection, theft-control, pressure management, or system-wide meter upgrade?

	1: Not important	2	3	4	5: Very important
Saving production costs					
Increased revenue					
Cost-benefit analysis					
Increase in system efficiency					

Reduced accidental leaks					
Met legal requirements					
Achieved target goals					
Improved reputation					

8. Which of the following would be or have been important reasons to initiate ACTIVE water-loss management?

	1: Not important	2	3	4	5: Very important
High level of water losses					
Financial pressure to reduce waste					
Grants or financial support					
Limited water supplies					
Other utilities' successes					
Leadership of managers					
Employee's suggestion					
Public or customer request					
Recommendations of governing board					
State requirement					

9. Please rate the importance of the factors in making active water-loss management successful.

	1: Not important	2	3	4	5: Very important
Financial feasibility					
External financial support					
Technology feasibility					
Technical assistance & Accessible information					
Political support					
Support from the public					
Legal obligation					
Internal advocates					
Qualified employees					
Rational organizational structure					

Effective internal communication system					
Evaluation procedures					
Clear purposes or targets					
Integrated efforts					
Long-term plans					

10. Do you disagree or agree with the following statements?

	Strongly Disagree	Disagree	Agree	Strongly Agree
Water loss is just a technical problem				
The amount of water lost is a good indicator of system efficiency				
Water-loss management is more effective than end-user conservation				
We are tracking how much water is lost in the distribution systems				
We are expecting legal obligations to reduce water losses in the future				
Our water-loss management is a part of our conservation program				
Our water-loss management is integrated with resource management				

11. Number of Employees and Departments in 2004

# of full-time employees	
# of certified employees	
Total # of employees	
# of departments	

12. Do you disagree or agree with the following statements about your organization?

	Strongly Disagree	Disagree	Agree	Strongly Agree
We need to be more competitive				
We are up to date with new technologies and management tools				
There are personal and organizational incentives for changes				
We are faced with more opportunities today				
Intergovernment relations impede our efforts for changes				
Environmental activism is intimidating				
Managers have flexibility to move funds across budget accounts				

Employees are familiar with the mission and agenda of our utility				
There is no confusion about roles and responsibilities				
Cross-functional work requires the intervention of supervors				
Our employees can make operating decisions by themselves				
Our workforce is homogeneous				
Our productivity is increasing (more water production per employee)				
It is more important to inform the public than to involve them in decision-making processes				
The number of customer complaints is increasing				
We evaluate system and organizational efficiency				
Other utilities have tried to learn from our successes				

13. How many days are usually needed to approve a new proposal for system improvement?

Days

14. Please rate the importance of information sources in your utility.

	1: Not important	2	3	4	5: Very important
Government (State agencies or EPA)					
Water Associations (AWWA, AMSA, AMWA, or regional)					
Suppliers selling equipment, devices, or tools					
Other water utilities					
Environmental or other civic organizations					
Universities/ Research centers					
Consultants					
Customers					
Board members					
Employees					
Internet					
Conferences/ Exhibitions					
Training/ Workshops					
Journals or publications					

15. How much did your utility spend obtaining information from the above sources ?

Average expenditures on information ($1,000/year)

16. Please describe the purposes/goals of your utility.

17. Water Volume (1,000,000 gal/ year) in 2004

Total Input to distribution system (produced & purchased)	
Billed Authorized	
Unbilled Authorized	

18. Production Costs in 2004

Total Annual Cost ($1,000)	
Production Cost ($/ 1,000,000 gal)	

19. Revenue in 2004

Total Annual Revenue ($1,000)	
From Volumetric Rates ($1,000)	

20. Water Rate in 2004

Average Rate ($/1,000 gal) for Residential customers	
Average Rate ($/1,000 gal) for Nonresidential customers	
Average Rate Increase (%) for last 5 years	

21. Please rate the importance of the following problems.

	1: Not important	2	3	4	5: Very important
Aging infrastructure					
Water quality					
Water allocation					
Increasing demand					
Limited water resources					
Reduction in revenue					
Increasing operation costs					
Asset management					
Need for outsourcing or co-sourcing					
Technology concerns					
System security					
Quality of customer service					
Legal obligations					
Support from government					
Relationship with the governing board					
Public Relations					
Cooperation with other water utilities					
Harmony among internal departments					
Need for organizational reform					
Short of qualified employees					
Water losses					

22. Do you want a final result of this survey and allow me to contact you for any additional questions?

	No	Yes
Survey result	☐	☐
Additional contact	☐	☐

23. If YES, please provide information about the person who answered these questionnaires

Name

Position

Department

Phone

E-mail

APPENDIX B

MORE RESULTS OF THE DATA ANALYSES

Table 18. Correlations in the AWWA Model (Loss/Mile)

	Loss/~e	Resid~l	Repla~e	log_li~_	log_d~_	Exten~e	_1995~s	_1994_~s	log(om)	Pop/s~e	Medium
Loss/~e	1.0000										
	250										
Resid~l	-0.0328	1.0000									
	245	245									
Repla~e	-0.0304	0.0207	1.0000								
	230	226	230								
log_li~_	0.1186	0.0368	0.2090*	1.0000							
	241	237	222	241							
log_d~_	0.0090	0.0854	0.1687*	0.6862*	1.0000						
	250	245	230	241	250						
Exten~e	-0.0539	-0.0734	0.3292*	0.3715*	0.3215*	1.0000					
	236	232	224	228	236	236					
_1995~s	0.0730	-0.0220	0.2596*	0.4490*	0.4343*	0.3755*	1.0000				
	250	245	230	241	250	236	250				
_1994~s	0.0554	-0.0037	0.2494*	0.4289*	0.4132*	0.3230*	0.9747*	1.0000			
	250	245	230	241	250	236	250	250			
log(om)	0.1065	0.0872	0.2835*	0.6998*	0.6431*	0.4297*	0.5938*	0.5725*	1.0000		
	250	245	230	241	250	236	250	250	250		
Pop/s~e	0.4088*	0.0045	-0.0055	0.0473	0.0732	-0.0961	0.0093	0.0193	0.1032	1.0000	
	239	234	219	232	239	226	239	239	239	239	
Medium	-0.0317	-0.0556	-0.0278	-0.1564*	-0.1428*	-0.0623	-0.0647	-0.0620	-0.2185*	-0.0461	1.0000
	250	245	230	241	250	236	250	250	250	239	250
EPA_6	-0.0549	0.1053	0.0253	0.1457*	0.1543*	0.0983	0.1689*	0.1014	0.0580	-0.0439	-0.0348
	250	245	230	241	250	236	250	250	250	239	250
log(p~)	0.2200*	-0.0820	0.2507*	0.7041*	0.6374*	0.4271*	0.6043*	0.5809*	0.9231*	0.1682*	-0.2112*
	250	245	230	241	250	236	250	250	250	239	250
Bill_Pri	-0.0747	0.2456*	-0.0138	0.1074	0.0760	-0.0045	0.0508	0.0609	0.0961	-0.0511	-0.0440
	245	245	226	237	245	232	245	245	245	234	245

	EPA_6	log(p~)	Bill_Pri
EPA_6	1.0000		
	250		
log(p~)	0.0651	1.0000	
	250	250	
Bill_Pri	-0.0751	0.0654	1.0000
	245	245	245

Table 19. Correlations in the AWWA Model (Loss %)

	loss__	precip~n	surfac~r	privat~r	log_in~e	_1995_~s	_1994_~s	log_m_	water~_	replace~e	EPA_6
loss__	1.0000										
	250										
precip~n	0.1495*	1.0000									
	250	250									
surface~r	0.1779*	0.1882*	1.0000								
	250	250	250								
private~r	-0.0573	0.1394*	0.0313	1.0000							
	250	250	250	250							
log_inc~e	-0.1573*	0.0299	-0.3070*	0.1028	1.0000						
	250	250	250	250	250						
_1995_n~s	0.0205	-0.0386	0.2177*	0.0946	-0.2198*	1.0000					
	250	250	250	250	250	250					
_1994_n~s	0.0045	-0.0576	0.2102*	0.1022	-0.2028*	0.9747*	1.0000				
	250	250	250	250	250	250	250				
log_o_m_	-0.1043	-0.1432*	0.2179*	0.1179	-0.1796*	0.5938*	0.5725*	1.0000			
	250	250	250	250	250	250	250	250			
water_d~_	-0.1746*	-0.0200	-0.0138	-0.1034	-0.0459	-0.0574	-0.0624	0.0164	1.0000		
	250	250	250	250	250	250	250	250	250		
replaced~e	-0.0690	-0.1456*	-0.0115	-0.0119	-0.1166	0.2596*	0.2494*	0.2835*	0.0037	1.0000	
	230	230	230	230	230	230	230	230	230	230	
EPA_6	-0.0478	0.0271	-0.0078	-0.0775	-0.0502	0.1689*	0.1014	0.0580	0.0461	0.0253	1.0000
	250	250	250	250	250	250	250	250	250	230	250

Table 20. Summary of the Variables in the AWWA Models

Variable	Obs	Mean	Std. Dev.	Min	Max
Loss_%	250	15.16292	11.4324	0	68.11318
Loss/Mile	250	2.348408	2.836378	0	22.93801
Residential Bill	245	226.5472	109.4672	13.06	833
Replaced Mile	230	4.116957	20.48187	0	300
log(liability)	241	6.976168	.9164946	4.271842	9.039968
log(debt)	250	6.928689	1.055868	0	8.941511
Extended Mile	236	8.932627	20.90144	0	166.3
Breaks_1995	250	161.096	335.4066	0	2751
Breaks_1994	250	176.48	391.5927	0	4054
log(O&M)	250	6.667747	.5781051	5.150474	8.248649
Pop/sq_Mile	239	3.148854	4.962608	.0245455	55.33333
Medium	250	.02	.1402808	0	1
EPA_6	250	.056	.230383	0	1
log(production)	250	3.617469	.6027487	2.522444	5.281488
Private Owner	250	.092	.2896057	0	1
Demand_Inc_%	250	8.6192	9.192779	-15	50
log(income_99)	250	4.649694	.1570888	4.371105	5.285911
Surface Water	250	.556	.4978508	0	1
Bill_Private	245	26.758	87.93418	0	500
Precipitation	250	35.09804	13.8851	2.71	82.1

Table 21. Correlations in the RFC Model (Loss %)

	Loss_%	Pop_~d	West	Max_sq	Purcha~	DB_~re	Cost ~p	Debt	Assets	Rate_I~	Mini~n	Empl~s
Loss_%	1.0000											
	130											
Pop_~d	0.0006	1.0000										
	128	128										
West	-0.3278*	0.0828	1.0000									
	130	128	130									
Max_sq	-0.0000	0.8751*	0.0131	1.0000								
	121	119	121	121								
Purcha~	-0.1468	-0.0098	0.1624	0.0131	1.0000							
	129	127	129	120	129							
DB_~re	0.3523*	0.0052	-0.3365*	-0.0161	-0.2462*	1.0000						
	128	126	128	119	127	128						
Cost ~p	-0.1068	0.1393	-0.0293	0.0387	-0.1352	-0.0618	1.0000					
	120	119	120	113	120	118	120					
Debt	-0.0083	0.7743*	0.2003*	0.5691*	-0.0586	-0.1004	0.1318	1.0000				
	106	105	106	100	106	105	105	106				
Assets	-0.0886	0.8059*	0.2193*	0.5554*	0.0119	-0.1457	0.1234	0.9282*	1.0000			
	111	110	111	103	111	110	109	103	111			
Rate_I~	0.1106	-0.1331	0.0454	-0.1089	0.1319	-0.3614*	-0.1428	0.0124	-0.0031	1.0000		
	125	123	125	116	124	125	117	103	108	125		
Mini~n	-0.1551	-0.1005	0.0054	-0.0974	-0.0116	-0.0116	0.0140	-0.1308	-0.1336	0.0038	1.0000	
	127	125	127	118	126	126	118	104	109	124	127	
Empl~s	-0.0352	0.8972*	0.1451	0.7386*	-0.0248	-0.0286	0.1219	0.8354*	0.8373*	-0.0714	-0.1007	1.0000
	124	123	124	117	124	122	118	104	109	119	121	124
Effici~y	-0.1095	0.1113	0.2513*	0.1028	0.1068	-0.1098	0.1831*	0.0011	0.0762	-0.2334*	-0.0166	-0.1035
	123	122	123	116	123	121	117	104	109	118	120	123

Table 22. Summary of the Variables in the RFC Model

Variable	Obs	Mean	Std. Dev.	Min	Max
Loss_%	130	11.87692	7.300861	0	36
Pop_served	128	455.4297	727.0976	13	5000
West	130	.3461538	.4775834	0	1
Maxprod_sq	121	51504.59	211523.2	16	1879641
Purchased_%	129	9.387597	26.27895	0	100
DB_Rate_Nonre	128	.3515625	.4793342	0	1
Cost Coverage	120	1.468201	.8232927	.6505554	8.954371
Debt	106	151988.3	242919	68	1135000
Assets	111	404171.2	558987.3	4561	3163991
Rate_industry	125	13240.04	6250.046	3689.36	34288.82
Mini_Charge_In	127	96.9622	144.6021	0	1241.9
Employees	124	273.5242	427.004	9	2334
Efficiency	123	.2797159	.1659769	.046519	.8858412

Table 23. Other Results of the EPA Model (Loss/Mile)

Linear regression							
				Number of obs = 436 F(14, 421) = 6.82 Prob > F = 0.0000 R-squared = 0.3586 Root MSE = .18665			
Loss/Mile	Coef.	Robust Std. Err.	t	P>|t|	95% Conf. Interval		Beta
log(Production)	.0825745	.0327038	2.52	0.012	.0182914	.1468576	.3783098
Connection/Mile	.0168373	.0063535	2.65	0.008	.0043488	.0293258	.3931186
Pipe_40yr_%	-.0007727	.0003059	-2.53	0.012	-.0013739	-.0001715	-.1038659
Efficiency	.0006013	.0003186	1.89	0.060	-.000025	.0012276	.2179055
log(Operation)	-.0996475	.0374778	-2.66	0.008	-.1733145	-.0259806	-.4067513
Conservation_R	-.0345054	.0206158	-1.67	0.095	-.0750281	.0060173	-.0660206
Residential Bill	.0001096	.0000565	1.94	0.053	-1.35e-06	.0002206	.0654801
Distribution_Ex	-.0006192	.0004009	-1.54	0.123	-.0014073	.0001689	-.0753923
Treatment_Ex	.0025387	.0006963	3.65	0.000	.00117	.0039074	.237109
G_DWSRF_%	-.0006867	.0003443	-1.99	0.047	-.0013635	-9.98e-06	-.0337535
B_DWSRF_%	.0015262	.0009924	1.54	0.125	-.0004245	.0034768	.1036233
Profit	-.0679727	.0307236	-2.21	0.027	-.1283634	-.0075819	-.0649677
All Metered	.0524276	.0196221	2.67	0.008	.0138582	.090997	.0997275
Lowincome_A	.0002888	.0248905	0.01	0.991	-.0486363	.0492139	.0003836
_cons	.3007336	.1247822	2.41	0.016	.0554598	.5460074	

Table 24. Correlations in the EPA Model (Loss/Mile)

	Loss/~e	log(Pr~)	Bill_Pr~	Con~/~e	Cons~R	Effic~y	G_DW~	B_DW~	log(Op~)	Dist~Ex	Trea~Ex	Resi~l
Loss/~e	1.0000											
log(Pr~)	0.2587*	1.0000										
Bill_Pr~	- 0.0321	-0.0037	1.0000									
Con~/~e	0.4275*	0.1964*	0.0774	1.0000								
Cons~R	-0.0215	0.1539*	-0.0284	0.0857	1.0000							
Effic~y	0.2996*	0.5626*	0.0223	0.0763	0.1021*	1.0000						
G_DW~	-0.0770	-0.1347*	-0.0337	-0.0802	-0.0444	-0.0860	1.0000					
B_DW~	-0.1246*	0.0087	-0.0536	-0.0480	-0.0582	0.0443	0.0866	1.0000				
log(O~)	0.1935*	0.9433*	0.0301	0.2178*	0.1740*	0.4736*	-0.1311*	-0.0178	1.0000			
Dist~Ex	0.1414*	0.4370*	-0.0130	0.1061*	0.1662*	0.1329*	-0.0438	-0.0335	0.4254*	1.0000		
Trea~Ex	0.2721*	0.3653*	-0.0202	0.0956*	0.0665	0.1569*	-0.0335	0.0410	0.3403*	0.6784*	1.0000	
Resid~l	0.0029	-0.1749*	0.3230*	0.0756	0.1257*	-0.0626	-0.0043	-0.0230	-0.0777	-0.0544	-0.0383	1.0000
P~40~%	-0.2575*	-0.2885*	-0.0622	-0.2249*	0.0627	-0.1590*	0.0712	-0.0681	-0.2236*	-0.0619	-0.1236*	0.1595*
All~red	0.0628	-0.0466	0.0120	0.0151	-0.0268	-0.0867	0.0261	-0.0295	-0.0262	0.0279	0.0205	-0.0439
Low~A	0.0468	0.1625*	-0.0704	0.0394	0.1262*	0.0608	-0.0410	-0.0105	0.1775*	0.2185*	0.1311*	0.0086

	P~40~%	All~red	Low~A
P~40~%	1.0000		
All~red	0.1326*	1.0000	
Low~A	-0.1145*	0.0425	1.0000

Table 25. Comparison between Inside and Outside the EPA Model (Loss/Mile)

. regress loss_pipe log_totalproductionrevised_   if model_1==1

```
     Source |       SS           df       MS                          Number of obs    =     436
-------------+------------------------------------                    F(  1,   434)    =   31.12
      Model |  1.52985905     1  1.52985905                           Prob > F         =  0.0000
   Residual|  21.3371847   434   .04916402                            R-squared        =  0.0669
-------------+------------------------------------                    Adj R-squared     =  0.0648
      Total   |  22.8670438   435  .052567917                         Root MSE         =  .22173
------------------------------------------------------------------------------
 Loss/Mile |      Coef.        Std. Err.       t       P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
log(Prod~) |   .0564572   .0101209      5.58   0.000     .0365652    .0763492
     _cons  |   -.030593   .0318042    -0.96   0.337    -.0931025    .031916
------------------------------------------------------------------------------
```

regress loss_pipe log_totalproductionrevised_   if model_1==0

```
     Source |       SS              df       MS                       Number of obs    =     373
-------------+------------------------------------                    F(  1,   371)    =   18.34
      Model |  15.9261069     1  15.9261069                           Prob > F          =  0.0000
   Residual |  322.119694   371  .868247155                           R-squared        =  0.0471
-------------+------------------------------------                    Adj R-squared    =  0.0445
      Total   |  338.045801   372  .908725273                         Root MSE         =   .9318
------------------------------------------------------------------------------
 Loss/Mile |      Coef.        Std. Err.       t        P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
log(Prod~) |   .1501961   .0350692     4.28   0.000     .0812368    .2191553
     _cons  |  -.1896629   .0938948    -2.02   0.044    -.3742957   -.0050302
------------------------------------------------------------------------------
```

Table 26. Summary of the Variables in the EPA Model (Loss/Mile)

Variable	Obs	Mean	Std. Dev.	Min	Max
Loss/Mile	436	.1366396	.2292769	0	2.4
log(production)	436	2.962114	1.050417	0	5.697425
Profit	436	.0504587	.219141	0	1
Bill_Profit	436	20.48394	98.76554	0	807
Connection/Mile	436	6.212713	5.35317	0	70.76471
Conservation_R	436	.2591743	.4386848	0	1
Efficiency	436	85.39482	83.08919	.4	678.8333
G_DWSRF_%	436	1.827982	11.26913	0	100
B_DWSRF_%	436	4.016055	15.56749	0	100
log(O&M)	436	5.905469	.9358857	3.341434	8.201233
Distribution_Ex	436	8.6391	27.9176	0	291.9801
Treatment_Ex	436	5.391561	21.41384	0	264
Residential Bill	436	282.8005	136.937	0	1046
Pipe_40yr_%	436	60.99312	30.8183	0	100
All Metered	436	.7454128	.4361293	0	1
Lowincome_A	436	.103211	.3045838	0	1

Table 27. Correlations in the EPA Model (Loss_Gross)

	Loss_G	Effic~y	P~80_%	Conn~1	Pipe~le	Conn~e	DW~%	Purch~r	Exp~%	Rep~10	R~6_10	Cost~e
Loss_G	1.0000											
	917											
Effic~y	0.0998*	1.0000										
	794	794										
P~80_%	0.0936*	-0.0394	1.0000									
	849	735	849									
Conn~1	0.3432*	0.0155	-0.0173	1.0000								
	891	772	828	891								
Pipe~le	0.5096*	0.0793*	0.0513	0.3969*	1.0000							
	812	696	787	795	812							
Conn~e	0.0680	-0.0027	0.0529	0.0059	0.0029	1.0000						
	806	691	781	795	806	806						
DW~%	-0.0276	-0.0520	0.0705	-0.0103	-0.0740	-0.0731	1.0000					
	677	609	632	659	605	601	677					
Purch~r	0.0729*	0.0557	0.1168*	-0.0110	0.0741*	0.0136	0.0999*	1.0000				
	917	794	849	891	812	806	677	917				
Exp~%	0.0210	0.1404*	-0.1067*	0.0661	0.1208*	-0.1120*	-0.0547	-0.0330	1.0000			
	655	588	612	638	586	583	639	655	655			
Rep~10	0.2384*	0.0464	0.0490	0.4358*	0.3623*	0.0502	-0.0088	0.0018	0.0275	1.0000		
	776	664	756	759	753	747	574	776	562	776		
R~6_10	0.3561*	0.0501	0.0214	0.6268*	0.5005*	0.0596	-0.0280	0.0359	0.0357	0.7613*	1.0000	
	783	672	761	765	759	753	582	783	570	770	783	
Cost~e	-0.0164	-0.0106	-0.0383	-0.0085	-0.0353	-0.0479	-0.0193	0.0426	0.0106	-0.0151	-0.0109	1.0000
	874	778	811	851	772	768	668	874	646	739	747	874
Prod~n	0.8642*	0.2283*	0.0413	0.2383*	0.4469*	0.0243	-0.0403	0.0676*	0.0710	0.2274*	0.2331*	-0.0182
	914	793	846	888	809	803	675	914	653	773	780	871

Table 28. Comparison between Inside and Outside the EPA Model (Loss_Gross)

. reg waterloss totalproductionrevised if model==1

Source	SS	df	MS
Model	5.7615e+09	1	5.7615e+09
Residual	1.7361e+09	447	3883963.62
Total	7.4977e+09	448	16735837.3

Number of obs	= 449
F(1, 447)	= 1483.41
Prob > F	= 0.0000
R-squared	= 0.7684
Adj R-squared	= 0.7679
Root MSE	= 1970.8

Loss_Gross	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
Production	.0775048	.0020123	38.52	0.000	.07355	.0814596
_cons	67.24265	95.25877	0.71	0.481	-119.968	254.4533

reg waterloss totalproductionrevised if model==0

Source	SS	df	MS
Model	1.9133e+09	1	1.9133e+09
Residual	752848416	463	1626022.5
Total	2.6662e+09	464	5746033.87

Number of obs	= 465
F(1, 463)	= 1176.68
Prob > F	= 0.0000
R-squared	= 0.7176
Adj R-squared	= 0.7170
Root MSE	= 1275.2

Loss_Gross	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
Production	.1015696	.002961	34.30	0.000	.095751	.1073882
_cons	-127.0145	62.09707	-2.05	0.041	-249.0415	-4.987477

Table 29. Correlations in the EPA Model (log(Loss))

	log(lo~)	log(Pr~)	B_P~%	Pipe_6	Nodebt	log(R~)	G_D~%	Conn~2	Deli~le	Effic~y
log(lo~)	1.0000									
	917									
log(Pr~)	0.7351*	1.0000								
	914	914								
B_P~%	-0.0839*	-0.0887*	1.0000							
	681	679	681							
Pipe_6	0.4031*	0.4252*	0.0043	1.0000						
	808	805	605	808						
Nodebt	-0.3641*	-0.4049*	-0.0354	-0.1876*	1.0000					
	839	836	642	740	839					
log(R~)	0.5170*	0.5416*	0.0022	0.2930*	-0.2433*	1.0000				
	837	834	625	808	765	837				
G_D~%	-0.1053*	-0.0922*	-0.0328	-0.0527	0.0201	-0.0199	1.0000			
	679	677	679	603	640	623	679			
Conn~2	-0.0048	-0.2536*	0.0334	0.0852*	0.0334	0.0653	0.0720	1.0000		
	891	888	663	791	818	819	661	891		
Deli~le	-0.0142	0.0879*	-0.0223	-0.0235	-0.0335	-0.0390	-0.0121	-0.2309*	1.0000	
	809	809	607	805	740	809	605	792	809	
Effic~y	0.2036*	0.5031*	-0.1039*	0.0304	-0.1073*	0.0743*	-0.0726	-0.5556*	0.1898*	1.0000
	794	793	612	693	754	719	611	772	695	794

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